Development of an IoT Temperature Fish Hold Monitoring System for Cooling Crab Fish Based on Hybrid Ice-Peltier with a Modified Finned Boiling Pot

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ABSTRACT

Small-scale blue swimming crab fishing vessels (<5 gross tonnage) commonly rely on conventional ice-based storage systems with limited temperature control and monitoring during onboard handling. This study presents an integrated onboard handling system that combines fishing vessel design analysis, a hybrid ice–thermoelectric (Peltier-based) smart fish hold, Internet of Things (IoT)-based real-time temperature monitoring, and a modified crab boiling pot equipped with damping fins. The vessel's general arrangement, hull form, and fineness coefficients were analyzed to assess their suitability for onboard boiling, handling, and storage activities. The smart fish hold was designed using ice as the primary cooling medium and supported by a thermoelectric module to stabilize the storage temperature. Temperature conditions inside the hold were continuously monitored using an IoT-based system with real-time alerts. In addition, damping fins were applied to the boiling pot to mitigate sloshing effects during vessel motion. The results indicate that the hybrid cooling system successfully maintained storage temperatures at approximately 4 °C, thereby supporting onboard cold chain requirements, while the monitoring system enabled continuous observation of thermal conditions. Overall, the proposed system demonstrates a

practical engineering solution for improving onboard quality management and operational safety on small-scale crab fishing vessels.

Keywords-blue swimming crab; smart fish hold; hybrid ice–Peltier cooling; IoT monitoring; small fishing vessel

I. INTRODUCTION

The Gebang Fishing Terminal (TPI) is a landing site located in the Gebang District, specifically in Gebang Mekar Village. It is situated along a tributary, and fishermen use five fishing gears: arad, nets, fishing rods, traps, and mini purse seines. The dominant catch and a favorite among the Gebang community is the blue swimming crab. The latter is a significant economic commodity, often arriving in large quantities at the TPI during the crab season.

Crab fishing activities require efficient fishing equipment to support successful fishing operations. Such equipment includes proper fishing vessels, particularly used for oceanic fishing. Vessels utilized for crab fishing are less than 5 Gross Tonnage (GT). They can be classified as small vessels and have limited space on board [1]. Their design determines the allocation of functional spaces for fishing operations, catch handling, and storage systems, which are critical for maintaining operational efficiency and product quality [2, 3]. Traditional shipbuilding processes often overlook the supporting facilities essential for successful fishing operations, the effectiveness of which is not only determined by the quantity of the catch, but also by its quality. Therefore, proper storage facilities are necessary to maintain the latter [4].

Handling of crabs differs from that of other catches. Once caught, the crabs are first boiled, then air-dried, and placed in a container filled with ice cubes [5]. Crab fishermen in Cirebon Regency use buckets or baskets to store their boiled catch. The lack of proper handling facilities can quickly degrade crab quality. To extend crab shelf life and address spoilage issues (during fishing, transport, storage, and marketing), cooling is necessary to maintain the freshness of the crabs for a specific period [6].

This problem can be addressed by implementing a cold chain in the post-harvest handling of crabs. Applying a cold chain, besides ensuring proper temperature control, can slow down the food spoilage process [7]. The cold chain can be implemented by modifying the onboard handling facilities. For instance, adding a thermoelectric cooling system and sensors in the hold can significantly improve the latter. The thermoelectric cooler in the hold can suppress high temperatures, achieve faster cooling, and extend the duration of ice. Peltier modules operate based on the thermoelectric effect, which is defined as the direct conversion of temperature differences into electrical voltage and vice versa. Peltier-based cooling systems offer several advantages, including small size, low cost, and environmentally friendly design, making them well-suited for cooling in electronic systems [8]. In addition to utilizing the Peltier module, sensors on the hold can detect temperature changes in real time using IoT and Artificial Intelligence (AI). Temperature monitoring in the hold ensures that the crabs remain at optimal temperatures, maintaining their quality and minimizing damage before they are landed. The use of wireless networks can facilitate the continuous flow of information that can be accessed at all stages of the cold chain [9]. Internal baffles or damping fins are commonly used in liquid containers operating under vessel motion to reduce sloshing effects and stabilize fluid movement [10].

Previous studies have typically investigated thermoelectric cooling, ice-based preservation, or IoT cold chain monitoring separately, without simultaneously considering vessel design constraints and onboard processing characteristics. In addition, most thermoelectric cooling applications have been developed under laboratory or land-based conditions and do not account for spatial limitations, vessel motion, and operational workflows commonly encountered in small-scale fishing vessels.

This study proposes an integrated fisheries engineering framework that links: (1) small-scale vessel design characteristics, (2) hybrid ice-thermoelectric cooling stabilization, (3) IoT-based real-time temperature monitoring, and (4) anti-sloshing boiling modification adapted to vessel motion. The integration of thermal management and vessel stability aspects represents a practical engineering contribution that is rarely addressed in onboard cold chain studies, particularly for vessels below 5 GT.

II. METHODS

The research was conducted in Gebang Village, Cirebon Regency, and the Fishing Vessel Design and Dynamics Laboratory of the Department of Fisheries Resource Utilization, IPB, from January to December 2024. The data collection location is shown in Figure 1.

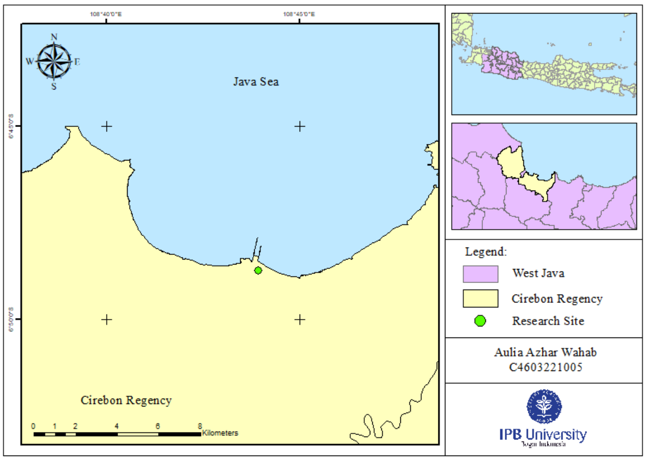


Fig. 1. Map of the research location.

The identification of the crab fishing vessels was carried out through direct observation and measuring their main dimensions, namely the folding trap vessels. The measurement results were used to establish a general design and a line plan for the sample vessel. After obtaining these designs, the next step was to create a fish hold model with internal dimensions of 46.5 cm in length, 36 cm in width, and 29.5 cm in height, while the external dimensions were 51 cm in length, 40 cm in width, and 36.5 cm in height. Modifications to the boiling pot involved altering the shape of the pan to resemble a box with dimensions of 55 cm in length, 55 cm in width, and 50 cm in height. The performance of the cooling system was evaluated based on cooling rate, minimum achievable temperature, and temperature stability over time.

The general design and outline plan of the folding trap ship obtained were analyzed descriptively by comparing them with the results of previous research. The ship's coefficients of fineness were calculated using [11]:

$$C_b = \frac{\nabla}{L\times B\times d} \qquad (1)$$

where C_b is the block coefficient, ∇ is the displacement volume (m^3), L is the length (m), B is the breadth (m), and d is the draft (m).

$$C_p = \frac{\nabla}{A\otimes\times Lwl}\frac{C_b}{C_m} \qquad (2)$$

where C_p is the prismatic coefficient, $A\otimes$ is the area of the middle area of the ship (m^2), and Lwl is the waterline length (m).

The midship coefficient C_m is given by:

$$C_m = \frac{A\otimes}{Bwl\times d} \qquad (3)$$

where Bwl is the waterline width (m).

The waterplane coefficient C_{wp} is given by:

$$C_{wp} = \frac{Aw}{Bwl\times Lwl} \qquad (4)$$

where Aw is the water plane (m^2).

The smart fish hold prototype consisted of an insulated cooler box, a thermoelectric module (TEC1-12706), an airflow circulation system, and an IoT-based temperature monitoring unit. Hybrid cooling was achieved using ice as the primary cooling source, supported by thermoelectric stabilization. A hysteresis control mechanism activated the thermoelectric module at 4.5 °C and deactivated it at 3 °C. Temperature data were transmitted wirelessly to a cloud-based platform and configured with a threshold alert at 5 °C to support real-time cold chain monitoring. This study emphasizes applied system integration rather than isolated component testing. Therefore, vessel geometry analysis, thermal system configuration, and monitoring architecture were evaluated as an integrated onboard handling system under realistic operational constraints of small-scale fishing vessels.

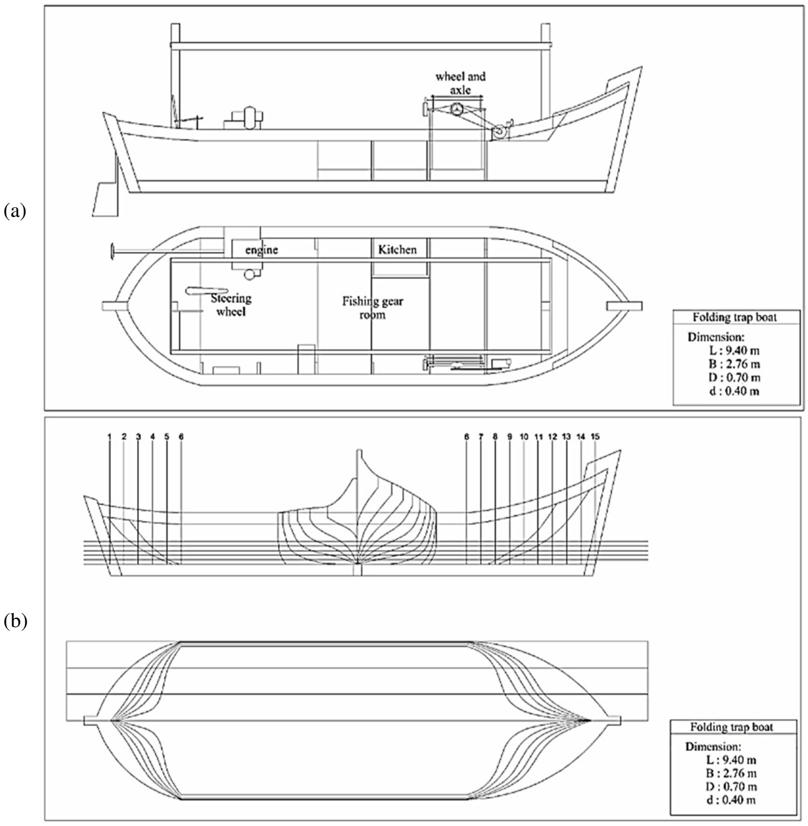


Fig. 2. Folding trap boat: (a) general arrangement, (b) lines plan.

III. RESULTS AND DISCUSSION

A. Specifications of Crab Fishing Boats in Cirebon

The dominant crab fishing vessel used by fishermen in Cirebon Regency is the folding trap boat, the characteristics of which are shown in Table I.

TABLE I. SPECIFICATIONS OF THE FOLDING TRAP BOAT

No	Specification	Type and size
1	Length	9.2-9.7
2	Breadth	2.6-3.1
3	Depth	0.6-0.7
4	Draft	0.4-0.5
5	Material	Teak wood
6	Number of fishing gears	1,200-1,600 units

The specifications of the folding trap boats are relatively uniform across different boats. This indicates no significant differences between the individual sample boats studied. Crab fishing vessels operate approximately 1,200-1,600 collapsible traps. Such a large amount of fishing gear can restrict movement on board. Furthermore, this increases the load on board, which can affect the vessel's capabilities.

Figure 2 depicts the design of a folding trap vessel. The general design of the crab fishing vessel features a division of workspace, comprising a boiling area in the midship, a product handling area, and a cooling fish hold utilizing a hybrid ice-Peltier system. The line plan of the trap vessel used has a U-bottom and double-pointed hull. The vessel with a U-shaped bottom, transversely, and a double-pointed shape lengthwise, can increase the power and stability of the ship [12]. The stability and maneuverability of a boat can be influenced by the shape of its hull [13, 14]. Ships with a U-shaped bottom tend to have a larger load capacity and provide superior stability [15]. This stable design ensures that onboard operations, such as boiling, airing, and storing crabs, can be conducted safely. Furthermore, this hull design is highly compatible with the implementation of automated or smart fish holds on small-scale fishing vessels [16, 17]. On a trapper boat, the axle motor is located on the right front of the vessel. This is because the hauling of the folding traps takes place there. The axle motor on a folding trapper boat facilitates the hauling of the traps onto the vessel.

B. Coefficients of Fineness of Folding Trap Boat

The ship's coefficients of fineness indicate the shape of the ship's hull below the waterline. These coefficients suggest the degree of ship fatness based on the relationship between the different hull areas and hull volumes of the ship to each of the ship's main dimensions. The values for the coefficients of fineness for folding trap ships are presented in Table II.

The coefficients of fineness calculation results indicate that the hull of the blue swimming crab fishing vessel is classified as full form, with characteristics that support operational needs at low to medium speeds. The prismatic coefficient (C_p) value of 0.734 is within the standard range of 0.56–0.80. This indicates efficient volume distribution from the midship area to the bow and stern, making it suitable for vessels operating under stop-and-go conditions and requiring high stability during the fishing and handling process on board. Higher C_b values generally increase the total resistance due to a larger wetted surface area and wave-making effects; however, this is not important for small-scale fishing vessels operating at low service speeds [19]. A fuller hull form improves initial transverse stability and provides greater internal volume for catch storage and onboard systems, including cooling installations [20, 21]. Therefore, the selected hull form represents a practical design compromise that prioritizes stability, functional capacity, and operational safety over high-speed performance.

TABLE II. COEFFICIENTS OF FINENESS OF FOLDING TRAP BOAT

Coefficients of fineness	Value	Typical range [18]
Prismatic coefficient (C_p)	0.734	0.56-0.80
Block coefficient (C_b)	0.711	0.39-0.70
Max midship coefficient (C_m)	0.969	0.63-0.91
Waterplane coefficient (C_{wp})	0.796	0.65-0.85

The maximum midship section coefficient (C_m) of 0.969 exceeds the reference range (0.63–0.91), indicating a nearly full midship form typically found in working vessels requiring high transverse stability during deck operations such as trap handling, onboard boiling, and catch transfer. The waterplane area coefficient (C_{wp}) of 0.796 falls within the standard range (0.65–0.85), suggesting a relatively large waterplane area that contributes to good initial stability against rolling motion. Overall, the combination of fineness coefficients indicates a full-form hull with large displacement volume and strong initial stability, making it suitable for low-speed crab fishing operations that require a stable platform for onboard processing and handling activities.

C. Smart Fish Hold Design

The smart fish hold system consists of an insulated cooler box integrated with thermoelectric modules, airflow circulation fans, and an IoT-based temperature monitoring unit powered by a 12 V electrical system (Figure 3). Hybrid cooling was achieved by combining ice with thermoelectric modules to enhance temperature stability. The system employed a TEC1-12706 Peltier module capable of reaching temperatures as low as −1.17 °C [22]. The thermoelectric unit has two heatsinks: a cold-side heatsink that cools the hold interior and a hot-side heatsink that dissipates heat, assisted by a blower fan to accelerate heat transfer. Temperature control was implemented using a hysteresis method, wherein the Peltier module activates when the temperature reaches 4.5 °C and deactivates at 3 °C. This configuration helped maintain stable storage temperatures and ensured efficient use of electrical energy during operation [23].

To verify component integration and operational functionality, the hybrid ice–Peltier cooling and IoT monitoring system was assembled in an experimental prototype configuration before onboard installation (Figure 4). This prototype stage was conducted to ensure the compatibility between thermoelectric modules, airflow circulation, insulation performance, and wireless data transmission under controlled conditions before field deployment.

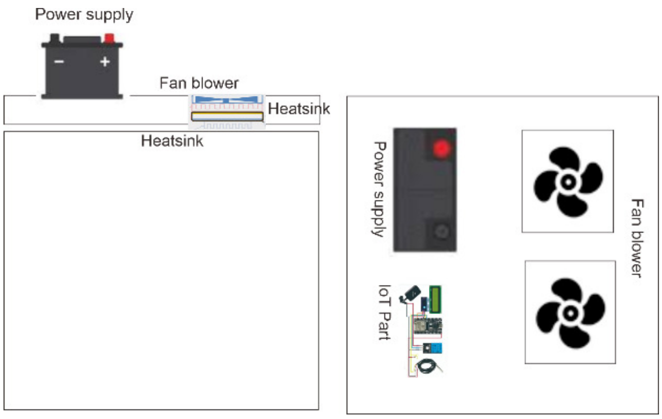


Fig. 3. Smart fish hold design.

Fig. 4. Experimental prototype configuration of the hybrid ice–Peltier smart fish hold and IoT monitoring system.

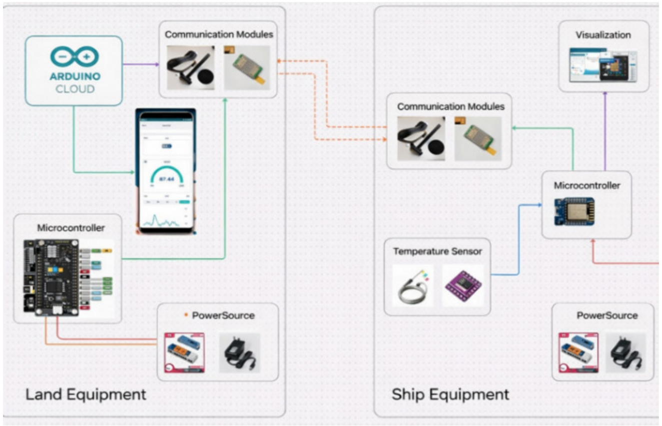


Fig. 5. Smart system on smart fish hold.

The smart fish hold incorporates an IoT-based monitoring architecture to enable real-time remote temperature observation. The system consists of two main units: an onboard sensing unit installed inside the fish hold and a remote monitoring unit connected through a cloud-based platform (Figure 5). The onboard unit continuously measures the storage temperature and transmits the data wirelessly for storage and analysis. Temperature information can be accessed remotely through an integrated cloud interface, while an automated alert mechanism is activated when the hold temperature exceeds the predefined threshold of 5 °C. This feature allows operators to perform immediate corrective actions, such as adjusting ice distribution or handling configuration. The overall workflow of the monitoring system is illustrated in Figure 6.

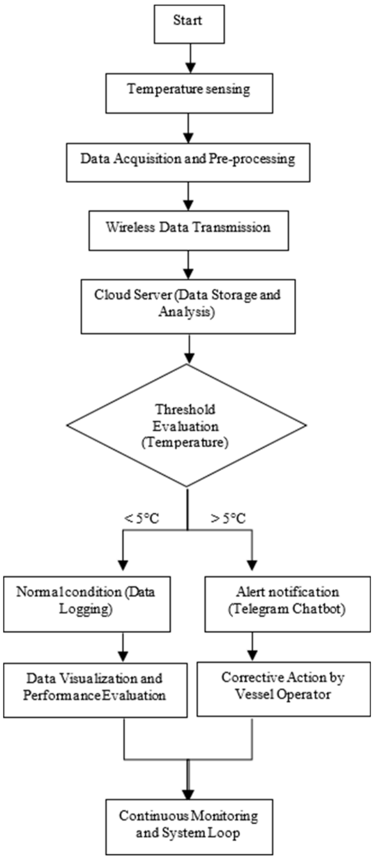


Fig. 6. Workflow of the fish hold temperature monitoring system.

The hold temperature monitoring dashboard features a numeric temperature indicator, system status, update time, and a time-series temperature graph with preset thresholds (Figure 7). These features enable continuous monitoring of hold thermal conditions, allowing for the detection of temperature deviations that could degrade crab quality. Presenting real-time and historical temperature data supports crab quality control during onboard storage, particularly in maintaining freshness and slowing post-harvest quality decline. The use of sensors for monitoring and assessing temperature changes is superior to traditional methods [24].

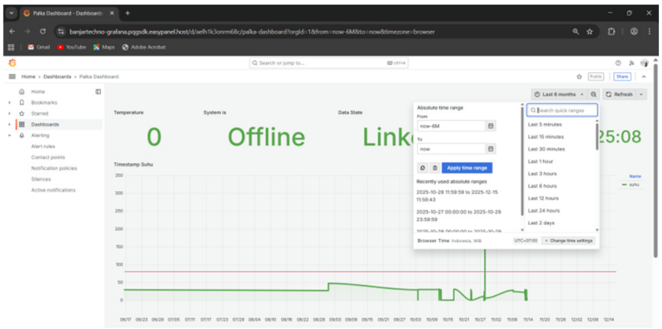
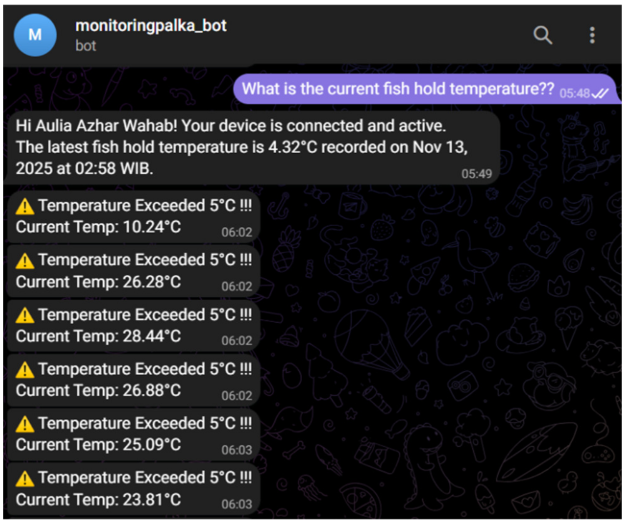


Fig. 7. Fish hold temperature monitoring dashboard.


monitoringpalka_bot
bot

What is the current fish hold temperature?? 05:48

Hi Aulia Azhar Wahab! Your device is connected and active.
The latest fish hold temperature is 4.32°C recorded on Nov 13, 2025 at 02:58 WIB. 05:49

⚠ Temperature Exceeded 5°C !!!
Current Temp: 10.24°C 06:02

⚠ Temperature Exceeded 5°C !!!
Current Temp: 26.28°C 06:02

⚠ Temperature Exceeded 5°C !!!
Current Temp: 28.44°C 06:02

⚠ Temperature Exceeded 5°C !!!
Current Temp: 26.88°C 06:02

⚠ Temperature Exceeded 5°C !!!
Current Temp: 25.09°C 06:03

⚠ Temperature Exceeded 5°C !!!
Current Temp: 23.81°C 06:03

Fig. 8. Temperature monitoring using Telegram chatbot.

The IoT architecture enables remote temperature monitoring through a cloud-based system with automated threshold alerts. A temperature limit of 5 °C is set to trigger notifications when the storage temperature reaches or exceeds this value (Figure 8). This approach supports early detection of cold chain deviations, reduces spoilage risk, and provides historical temperature data for evaluating storage performance and onboard handling practices. Consequently, the system helps improve product quality consistency and minimize post-harvest losses.

The IoT-based smart fish hold converts conventional ice storage into a data-driven thermal management system. Unlike traditional methods that rely on manual inspection and periodic ice adjustment, the proposed configuration enables continuous real-time temperature measurement and wireless data transmission during fishing operations. This improves monitoring accuracy and supports temperature stability, which is crucial for maintaining the quality of boiled crab during onboard storage. The resulting temperature profile is displayed in Figure 9.

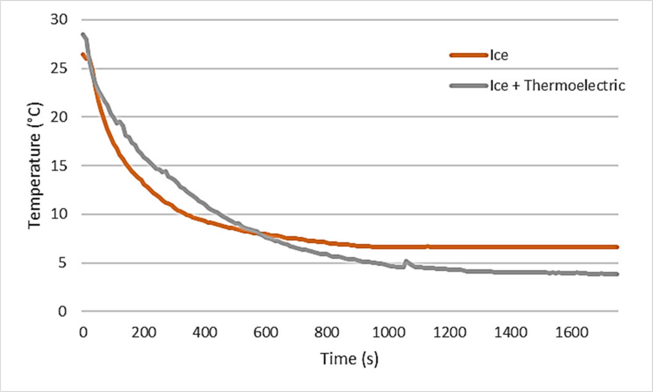


Fig. 9. Results of temperature measurements on the fish hold.

Figure 9 portrays the relationship between the time and temperature inside the smart fish hold during the cooling process. The temperature decreased rapidly from approximately 27–29 °C during the first 200–400 s and then declined more gradually until it stabilized at around 4 °C after about 1200–1500 s. The hybrid ice–thermoelectric configuration achieved a lower and more stable temperature than the ice-only condition, which is suitable for suppressing enzymatic and microbial activity in boiled crab and maintaining cold chain quality during onboard storage.

The hybrid ice–Peltier smart fish hold was designed to address common constraints in vessels below 5 GT, such as limited deck space, restricted electrical capacity, and manual handling operations. The system integrates thermal stabilization and IoT-based monitoring within a compact insulated unit adapted to the vessel's general arrangement.

The experimental prototype represents a system integration stage prior to full onboard implementation, demonstrating the technical feasibility of the design under realistic operational conditions and emphasizing its practical application in small-scale fisheries engineering.

Previous studies have typically examined thermoelectric cooling systems and IoT-based cold chain monitoring separately. Thermoelectric cooling is commonly applied in portable refrigeration or electronic thermal management without considering vessel operational conditions and onboard handling constraints [8]. In contrast, IoT cold chain research mainly focuses on temperature tracking and data transmission in land-based food logistics systems [9, 24]. This study integrates vessel design parameters, a hybrid ice–Peltier cooling configuration, real-time IoT monitoring, and onboard boiling workflow into a unified small-scale fisheries engineering framework tailored to the spatial and operational limitations of traditional fishing vessels.

D. Boiling Pot Design with Damping Fins

The boiling pan was modified by changing its geometry and adding internal damping fins made of food-grade stainless steel (SS 304/316). These fins were installed inside the pan to suppress fluid movement, particularly during crab boiling and vessel motion. The modified boiling pan with damping fins is shown in Figure 10.

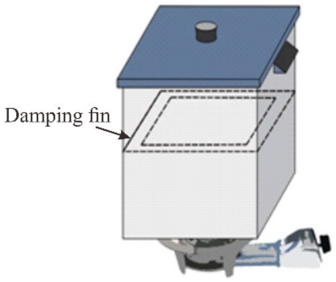


Fig. 10. Modified crab boiling pot with damping fins.

The innovation of the boiling pot with damping fins was developed to overcome fluid instability during boiling the crabs on fishing boats experiencing wave motion. Instability in the form of sloshing causes irregular heat distribution, increases the risk of hot water spills, and decreases heating efficiency. The application of damping fins (anti-sloshing baffles) was adapted from fluid stabilization technology used in ship tanks and industrial liquid storage systems, and then tailored to meet the specific needs of the food boiling process in the maritime environment. The size of the baffles directly affects the anti-sloshing performance [25]. Avoiding the sloshing effect can be accomplished by making an accurate estimate of the fluid flow [26].

From a safety perspective, the fin structure reduces the risk of hot water spills during vessel rolling and pitching. The movement of the free liquid surface can generate sloshing that produces hydrodynamic impact forces and may affect vessel motion and dynamic stability [27]. Experimental and numerical studies have shown that internal damping structures, such as baffles or fins, can mitigate free-surface deformation and reduce the dynamic pressure inside partially filled tanks [28]. These structures also suppress sloshing amplitude and decrease the velocity of liquid motion within the tank [29, 30]. Thus, this innovation not only has a technical impact on product quality but also supports crew safety and operational efficiency.

IV. CONCLUSIONS

This study demonstrates that the collapsible crab fishing vessels operating in Cirebon Regency exhibit full-form hull characteristics with high transverse stability, making them technically suitable for integrating onboard processing and cooling systems. The calculated fineness coefficients indicate that the vessel configuration supports low-speed operation with sufficient load capacity and stable deck conditions required for crab boiling and handling activities.

The developed hybrid ice–Peltier smart fish hold maintained a stable storage temperature of approximately 4 °C, lower and more consistent than conventional ice-only storage systems. The integration of hysteresis-based thermoelectric control with real-time Internet of Things (IoT) monitoring improves temperature stability and strengthens cold chain reliability under the operational constraints of small-scale fishing vessels.

The proposed system applies an integrated engineering approach that combines vessel stability analysis, hybrid thermoelectric cooling, IoT-based temperature monitoring, and a finned boiling unit designed to reduce free-surface effects during onboard processing. This integration addresses spatial limitations and vessel motion characteristics that have been rarely considered simultaneously in previous studies.

The damping-fin boiling design improves thermal uniformity and operational safety by minimizing fluid movement under wave-induced motion. Overall, the integrated configuration provides a practical applied fisheries engineering solution for enhancing onboard cold chain implementation, improving product quality consistency, and reducing post-harvest losses in small-scale crab fisheries.

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