Development and Performance Testing of Mini Cooler Vapor Compression for Improving the Quality of Fish Caught by Fishermen

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Abstract. The need for refrigeration in storing fishermen's catches is crucial. A solar-powered cooling system is highly necessary during fishing trips, as no electrical energy is available on fishing boats. The objective of this study is to develop a mini cooler with a solar-powered vapor compression refrigeration system to improve the quality and extend the shelf life of the fish catch. The method used involves the design and testing of the system, in which a vapor compression refrigeration unit powered by solar panels was built to cool 5 kg of fish, and its performance was tested. The parameters measured include evaporator and condenser temperatures, cooling capacity, system performance (COP), as well as fish quality and shelf life. The results showed that the solar-powered vapor compression refrigeration system operated optimally, with system performance indicated by a COP value of 2.24–2.42. Therefore, the findings suggest that this system is feasible for further development with a larger capacity to support small-scale fishermen in improving their businesses.

Keywords: Cooling System, Fish Quality, Solar power, System Performance

1 Introduction

As an archipelagic country with the world's second-longest coastline, Indonesia holds great potential in the fisheries sector. However, the highly perishable nature of fish remains a major challenge in maintaining catch quality, particularly for small-scale fishermen with limited access to refrigeration infrastructure (Widianto & Fauzi, 2018). Fish spoilage is primarily caused by enzymatic activity and bacterial growth that accelerate after the fish dies, making proper and immediate handling essential to preserve freshness and economic value.

Traditional methods, such as the use of ice blocks, present limitations in terms of efficiency and practicality, especially under operational conditions at sea. The vapor compression refrigeration system offers a more reliable cooling technology compared to ice blocks (Widianto & Fauzi, 2018). However, its reliance on conventional electricity poses challenges in remote areas or for fishermen with limited access to the

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power grid. Utilizing solar energy as an alternative power source provides an attractive and sustainable solution.

Several studies have been conducted on the design and development of solar-powered refrigeration systems. For example, the use of Peltier modules for mini cooling boxes has been investigated, offering an eco-friendly cooling solution capable of preserving products such as fish, vegetables, and other perishables (Haryanti el a., 2022). The coefficient of performance (COP) when using PLN electricity at 25 °C only reached 2.2286, while solar panel operation allowed the COP to reach 2.4663. However, the COP gradually decreased as the temperature approached 0 °C (Lubis et al., 2022). There has been limited research on the development of solar-powered vapor compression refrigeration systems for fish preservation, particularly for use by fishermen at sea.

In the context of developing sustainable and practical cooling systems for fisheries, it is also crucial to consider the concept of appropriate technology, which provides a framework for designing solutions that are tailored to local needs and conditions. In general, appropriate technology can be defined as technology designed for a specific community so that it can be adapted to the environmental, ethical, cultural, social, political, and economic aspects of that community (Sianipar et al., 2013). Both Schumacher and many modern advocates of appropriate technology also emphasize that appropriate technology is fundamentally human-centered, focusing on the needs and capabilities of its users (Akubue, 2000; Sianipar et al. 2014).

Appropriate technology related to fish preservation has been widely studied. For example, an experimental study employed a solar-powered thermoelectric cooling (STC) system to store Pangasius bocourti fillets for 10 days, achieving a COP of approximately 0.44. The study concluded that STC is an environmentally friendly alternative for areas without reliable electricity access (Biswas et al. 2021). Thermoelectric technology, developed without refrigerants and offering portability, as well as stable temperature control, has been considered an appropriate option for cooling in off-grid areas. Although its efficiency is still lower compared to vapor compression systems, this technology holds significant potential for further development (Kaiprath & Kumar, 2023).

This study aims to develop a portable solar-powered vapor compression mini cooler with a cooling capacity of 1/8 HP that is simple to operate. The system is designed to improve the quality and extend the shelf life of fishermen's catches while reducing dependence on fossil fuels and lowering operational costs. The mini cooler is expected to serve as a practical solution for fishermen to preserve fish freshness, reduce post-harvest losses, increase income, and support government programs promoting renewable and environmentally friendly energy. Additionally, this research utilizes computer applications such as Dancap and Coolpack for system calculations and component selection, ensuring an optimal design of the refrigeration system.

2 Methodology

2.1 Design

This study employs an experimental method by developing a prototype of a solar-powered mini cooler, as shown in Figure 1. The performance of the prototype is then tested through experiments conducted under two conditions: without a load and with a load of 5 kg of fish.

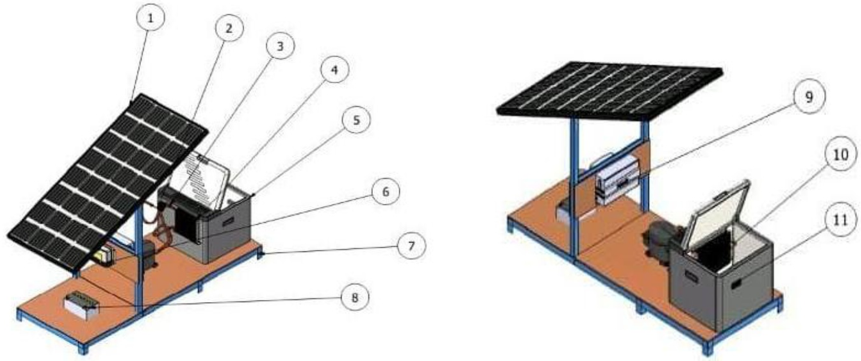

Figure 1. Design of a Mini Cooler

Information:

1. Solar Panel
2. Capillary Tube
3. Filter Dryer
4. Condenser
5. Cooling Box
6. Solar Control Panel
7. Frame
8. Battery
9. Inverter
10. Evaporator
11. *Thermo* Meter

The capacity of the solar panel used was determined based on the cooling load, namely 5 kg of fish, which required a compressor power of 100 W as calculated. To meet this demand, a solar panel capacity of 230 WP × 4 with a series–parallel configuration was employed. The specifications of the other components include a condenser with a capacity of 0.37 kW, an evaporator capacity of 0.29 kW, a 12 V 12 Ah battery, and a 12 V DC 30 A Solar Charge Controller (SCC). A cooling box with a capacity of 5 kg was selected as the prototype model to determine the cooling load and to serve as the basis for planning the other refrigeration components. For larger capacities, the system can be scaled up accordingly.

2.2 Determination of Data Sources

The data were obtained through direct testing of the fabricated device. Data collection was carried out once the system reached stable operating conditions. After achieving normal operation, data were immediately recorded, and the testing was repeated three times with a 5-minute interval between each measurement.

2.3 Research Procedures

This study was conducted in several stages, starting with a field survey to identify community needs and determine the design and mechanism of the system. The next stage involved developing the machine design, which produced working drawings, followed by the fabrication process. Once the unit was completed, performance testing was conducted. The tests were carried out between 10:00 a.m. and 2:00 p.m. local time to ensure full sunlight as the primary energy source. Performance evaluation was conducted under two conditions: without load and with load, using 5 kg of fish. After the test data were collected, data analysis was performed to evaluate the system's performance in accordance with the initial design plan. Data collection for the system was carried out at several temperature and pressure measurement points, as shown in Figure 2. T1 represents the compressor inlet temperature, T2 the compressor outlet temperature, T3 the condenser outlet temperature, while T4, the evaporator inlet temperature, was not measured since the enthalpy remains constant between points 3 and 4. TEvap denotes the temperature measured at the evaporator. Pressure was measured at the compressor suction side as the low pressure, and at the compressor discharge side as the high pressure.

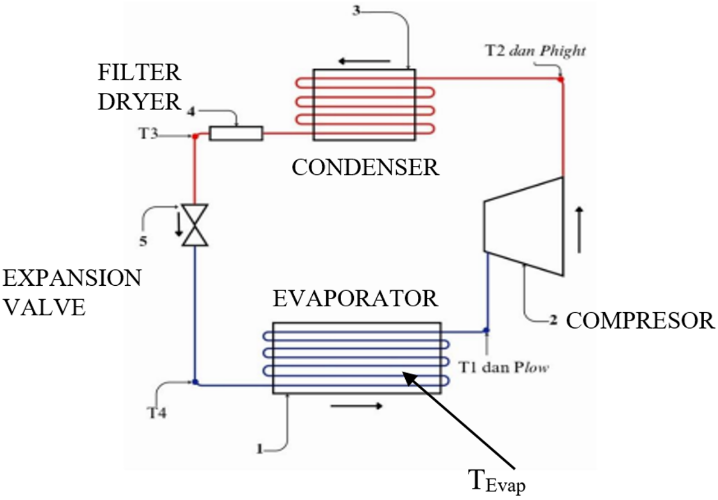

Figure 2. Position of Temperature and Pressure Measurement Points in the System

2.4 Data analysis

In this study, the data analysis method used is a descriptive quantitative method. The temperature and pressure data obtained from the measurement points were then plotted on a P-h diagram to determine the enthalpy values. These enthalpy values were used to calculate the system's performance by determining the COP.

3 Result and Discussion

3.1 Prototype results

The result of the design was realized in the form of a prototype, and the prototype of the solar-powered mini cooler is presented in Figure 3.

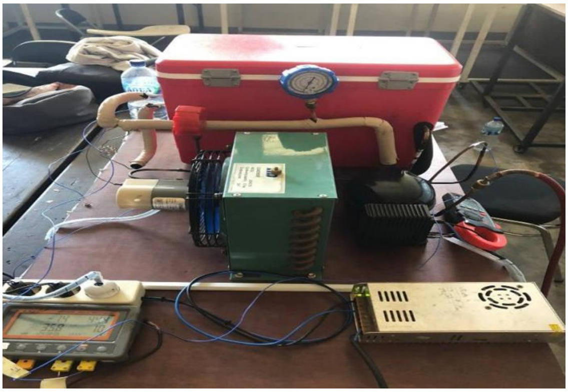

Figure 3. The Prototype Product is a Solar-Powered Vapor Compression Mini Cooler for Fish Storage with a Cooling Capacity of 1/8 PK

3.2 Test result

The test results of the system, measured at the evaporator temperature by comparing the conditions without a cooling load and with a cooling load of 5 kg of fish, are presented in Figure 4.

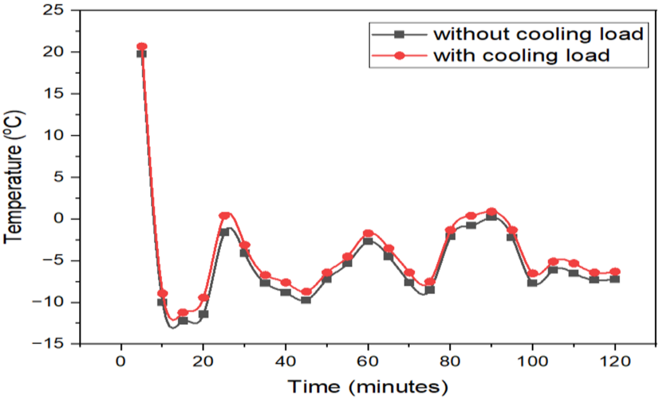

Figure 4. Evaporator Temperature Versus Time Under Loaded and Unloaded Conditions

Based on the test results shown in Figure 4, it can be observed that when the system was operated with a cooling load of 5 kg of fish, the evaporator temperature was higher compared to the unloaded condition. This occurred because the cooling load (fish) absorbed the evaporator's achieved temperature, resulting in consistently higher temperatures under loaded testing than without a load (Baliarta & Yusuf, 2024). Overall, the system was able to operate properly, as indicated by the evaporator temperature, which represents the cooling box temperature remaining within a safe range for preserving fishermen's catch, namely between 1 °C and –11 °C at the evaporator, ensuring that the cooling box temperature was maintained safely within 5 °C to –5 °C.

Based on the temperature measurements at the compressor inlet (T1), compressor outlet (T2), and condenser outlet (T3), as well as the observed pressures—low pressure and high pressure—the presented results are the average measurements taken over 120 minutes, as shown in Table 1.

Table 1. Test Results Data

Condision	T_{evap} (°C)	T1 (°C)	T2 (°C)	T3 (°C)	Hp (Psi)	Lp (Psi)
Without Load	-5.05	-2.05	72	32	123.37	27.55
With a Load of 5 Kg	-3.98	-0.98	80	35	132.08	26.11

The pressure and temperature measurement data were plotted on the P-h diagram as shown in Figures 5 and 6.

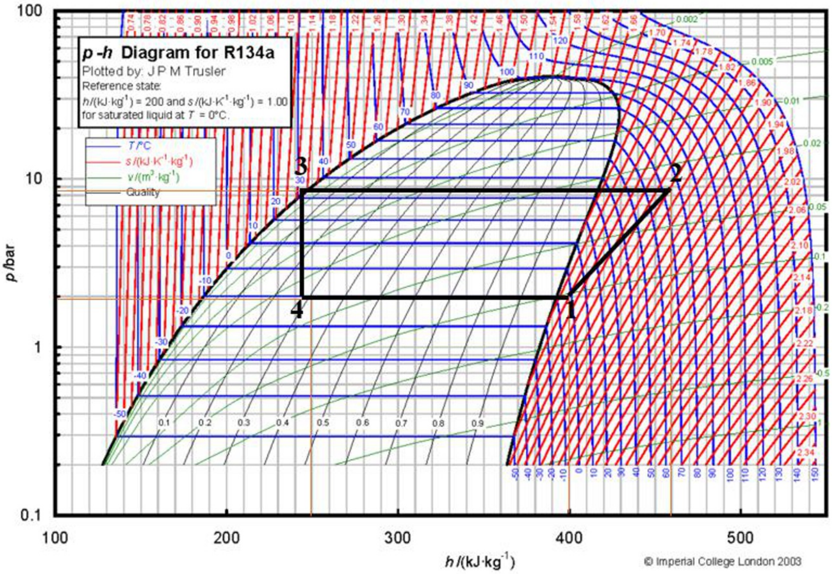

Figure 5. P-h Diagram Without Cooling Load

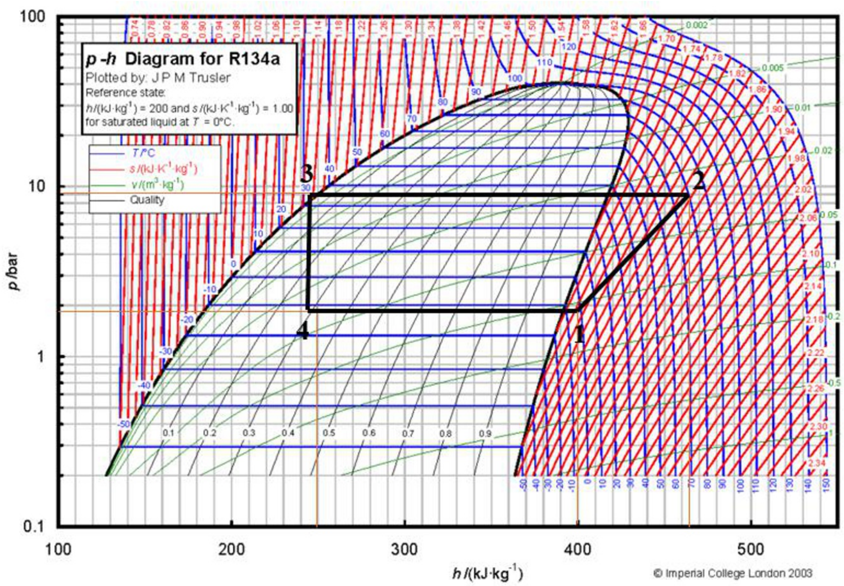

Figure 6. P-h Diagram With Cooling Load

From Figure 5, which shows the P-h diagram of the mini cooler system without cooling load, the enthalpy at the compressor inlet (h1) is 400 kJ/kg, and the enthalpy at the compressor outlet (h2) is 460 kJ/kg. The enthalpy at the condenser outlet (h3=h4) is 245 kJ/kg. For the enthalpy with cooling load (5 kg of fish), the enthalpy at the compressor inlet (h1) is 400 kJ/kg, the enthalpy at the compressor outlet (h2) is 465 kJ/kg, and the enthalpy at the condenser outlet (h3) is 245 kJ/kg.

3.3 Discussion

Coefficient of Performance (COP) Mini Cooler Without Load. Based on Figure 3, the refrigeration effect and compressor work of the mini cooler system can be calculated by dividing the refrigeration effect (ER) by the compressor work (Wk). The refrigeration effect (ER) in the mini cooler without load is calculated as follows:

$$ER = h1 - h4 \tag{1}$$

Where:

ER = Refrigeration Effect
$h1$ = Refrigerant enthalpy at the evaporator outlet (kJ/kg)
$h4$ = Refrigerant vapor enthalpy at the compressor outlet (kJ/kg)

With $h1$ of 400 kJ/kg and $h4$ of 245 kJ/kg, the refrigeration effect (ER) obtained from Formula (1) was 155 kJ/kg. For the compressor work (Wk), it is calculated using the following formula:

$$Wk = h2 - h1 \tag{2}$$

Where:

Wk = Compressor Work
$h2$ = Refrigerant vapor enthalpy at the compressor outlet (kJ/kg)
$h1$ = Refrigerant vapor enthalpy at the compressor inlet (kJ/kg)

For the compressor work (*Wk*), with $h2$ of 460 kJ/kg and $h1$ of 400 kJ/kg, the value obtained from Formula (2) was 60 kJ/kg. Therefore, the compressor work of the mini cooler is 60 kJ/kg. The obtained values of refrigeration effect and compressor work are then used to calculate the *COP* using the following formula:

$$COP = \frac{ER}{Wk} \quad (3)$$

With a refrigeration effect (*ER*) of 155 kJ/kg and a compressor work (*Wk*) of 60 kJ/kg, the coefficient of performance (*COP*), calculated as the ratio of ER to Wk, was obtained as 2.58, indicating that the prototype of this solar-powered mini cooler can be categorized as having fairly good performance.

Coefficient of Performance (COP) Mini Cooler With Load. Based on Figure 4, the refrigeration effect and compressor work of the mini cooler system with a cooling load of 5 kg of fish can be calculated. The refrigeration effect (ER) of the mini cooler with load has been determined using formula (1), where the enthalpy difference *h1-h4* (with *h1* of 280 kJ/kg and *h4* of 130 kJ/kg) gives a value of 150 kJ/kg. Furthermore, the compressor work (Wk) was obtained through formula (2), calculated from the enthalpy difference *h2-h1* (with *h2* of 345 kJ/kg and *h1* of 280 kJ/kg), resulting in 65 kJ/kg. Based on these values, the coefficient of performance (COP) was then calculated using formula (3), which expresses the ratio of ER to Wk. The COP obtained from the mini cooler prototype with a cooling load of 5 kg of fish is 2.30.

A decrease in system performance is observed, indicated by the reduction of the system's COP before and after applying the cooling load, from a COP of 2.58 to 2.30. This condition is considered reasonable, as the cooling load requires the system to absorb more heat, which in turn demands greater energy to maintain low temperatures. However, the increase in input power is often proportionally higher than the increase in refrigeration effect, causing the system's COP to decrease (Santosa et al., 2018; Amrullah et al., 2017; Buntu et al., 2017; Hasanudin et al., 2023; Pottker & Hrnjak 2015; Rachman & Lisa, 2018).

4 Conclusion

Based on the results of this research, several conclusions can be drawn. The prototype of the solar-powered mini cooler has been proven to operate properly, which shows that the system functions as expected. In addition, the use of this solar-powered mini cooler is considered feasible, since the temperature inside the cooling box remains within the safe range to maintain fish freshness, namely between 5 °C and –5 °C. Moreover, in terms of performance, the COP of the mini cooler system without a cooling load is 2.58, whereas under a cooling load, the COP decreases to 2.30. This means that there is a reduction in COP of 0.28 after the system is subjected to the cooling load. Therefore, it is suggested that future development focuses on increasing the storage capacity of the system so that it can accommodate a larger quantity of fishermen’s catch.

Acknowledgment

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