Design innovation of fish cooling system using liquefied petroleum gas fuel

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Abstract. Fresh fish is known as one of the highly perishable foods. Losses in the primary fish harbor and seafood production are significant, with discarding rates between 9-15%, and more losses occur during fresh fish distribution. This research was an effort to provide better fresh fish distribution equipment using a refrigerator cooling system with Liquefied Petroleum Gas (LPG) fuel generator as a power source. LPG was chosen because it is more economical and profitable than gasoline. Based on fuel consumption, LPC was 40.71% lower than premium gasoline, 62.63% lower than pertamax gasoline, and 64.85% lower than pertamax plus gasoline. The calculation of refrigeration heat load was carried out by applying heat transfer theory. Since the refrigeration heat load obtained was 310 Watt, then the type and capacity of the generator was easily determined.

1. Introduction

Indonesia is one of the transitional countries in the world with rudimentary post-harvest infrastructure for seafood products. Generally, only high economical seafood products destined for export are appropriately handled and supported with excellent infrastructure. Fish caught by traditional fishermen, on the other hand, has not been handled well. Consequently, the quality of fish decreases significantly during handling, and the price becomes cheap.

Generally, the supply chain of seafood products in Indonesia consists of two stages, i.e., the primary fish or seafood production from the sea to the fishing port and distribution from the port to the market or consumers. A large amount of stale fish present during supply chain and distribution mainly caused by poor handling during post-harvesting. Food losses take place during production, post-harvest, and processing stages in the food supply chain [4]. Losses in primary fish and seafood production are significant, with discarding rates of between 9-15%, and more losses may occur during fresh fish distribution [3]. Unfortunately, this situation forced some fishers and traders to use formalin as a fish preservative. More than 60% of fishery products, especially salted dried fish in traditional markets and supermarkets in East Java, tested positive for formaldehyde [5].

Fish are a commodity with high economic value and a source of protein with affordable prices and abundant quantities. Proteins from fresh fish are essential nutrients for growth and as constituents of the body’s cells [2]. Therefore, it is necessary to maintain the freshness of fish during harvesting and distribution. One of the means to sustain the fish freshness is through intimate contact between fish and small pieces of ice. However, large amounts of ice can reduce capacity in the storage and not sufficient to keep storage temperature low during the distribution process. Therefore, this research was
an effort to improve fish handling during distribution using a refrigerator cooling system with an LPG fuel generator as a power source. The use of LPG as the fuel of the generator based on the fact that LPG is cheaper than diesel or gasoline. Besides, LPG is more environmentally friendly with abundant resources in Indonesia.

2. Methodology
The first stage of this research was a survey to identify problems in the supply chain and real condition of fresh fish distribution to the markets or directly to consumers. Based on the territorial condition and poor transportation facilities, the cooling box system on the three wheels motorcycle concept has been determined. The dimension of this cooling box was 1.2 m length, 1.2 m breadth and 1 m height. The storage capacity was 300 kg with 200 mm insulation. The cooling box was constructed using aluminium, polyurethane, and fiberglass, respectively, from the outside to the inside parts. The fuel of the generator, which originally used gasoline, was substituted by Liquefied Petroleum Gas (LPG). The comparison fuel consumption of gasoline with LPG was calculated as shown in Table 1.

The second stage was the product load determination done by calculating product load, insulation heat load, air change heat load and electrical load needed. Primary refrigeration loads from products brought into and kept in the refrigerated space were the heat that must be removed to bring products to storage temperature and heat generated by-products in storage. Styrofoam insulation with 0.1 m thickness is used, while the conductivity is 0.03 Kcal/m2h°C. The insulation heat leak through walls, roof, and the floor was calculated by Equation 1[1,2].

\[ Q = A \cdot c \cdot \Delta T \]  
(1)

Where \( A \) was the surface area of storage, \( c \) was conductivity of the insulation materials, and \( \Delta T \) was the temperature difference between ambient and storage were 35°C and -5°C.

The heat of air changes refrigerator calculated by multiplication of 2.7 air changes in 24 hours with storage volume and heat gain 40 Kcal/m3 at the worst-case assumption of 35°C and 60% RH, as shown in Equation 2[1].

\[ Q = \frac{Vol_{store} \times Heat_{gain} \times ACH}{24} \]  
(2)

The product load heat or heat removed to freeze the product was calculated by multiplying latent heat of fish product and amount of fish product per 24 hours, as shown in Equation 3[1,2].

\[ Q = m \cdot h_f \]  
(3)

Where \( m \) was the weight of the product, and \( h_f \) was latent heat of fusion of the product.

The load of the refrigerator was calculated by adding up all items of heat transfer, respectively. Finally, based on the heat load calculation result, the power needs to operate the refrigerator was estimated.

3. Results and Discussion
3.1. Design Concept
The design concept of the cooling box on three wheels motorcycle is presented in Figure 1.
Figure 1. Design of Mobile Cooling System using an LPG as fuel for generator.

Note: (1) power source to operate the refrigerator, placed behind the cooling box, (2) cooling box insulation with polyurethane material which contain air cavity to ensure the cooling trap, (3) set of refrigerator system with racking arrangement, (4) three wheels motorcycle for primary transportation device, (5) LPG as fuel to turn on the generator, (6) converter kit to adjust LPG fuel, (7) generator engine, and (8) fish product.

Three wheels motorcycle was selected based on the Indonesian geographical condition in which the fish port located in a remote area. Small scale fisheries conducted by traditional fishermen were unprofitable to serve the massive transportation infrastructure so that this concept will be a solution to the problem. Ice blocks used for cooling fish during transportation to markets and consumers were not effective due to the Indonesian weather condition where the ice melts quickly during transport. The refrigerator system should be carefully selected to keep the temperature low. Refrigerator power was supplied by a generator placed behind the cooling box, which was operated by LPG-fuel. Comparisons of generator fuel consumption illustrated in Table 1.

| Fuel                  | Unit | Distance (km) | Price (IDR) | Cost (IDR/km) |
|-----------------------|------|---------------|-------------|---------------|
| Premium gasoline      | L    | 66.38         | 6,500       | 97.92         |
| Pertamax gasoline     | L    | 71.12         | 11,050      | 155.37        |
| Pertamaxplus gasoline | L    | 76.59         | 12,650      | 165.17        |
| LPG                   | Kg   | 86.12         | 5,000       | 58.06         |

Table 1 shows that the cost of using LPG fuel was 40.71% lower than premium, 62.63% lower than pertamax gasoline, and 64.85% lower than pertamax plus gasoline.

3.2. Heat Load Calculation

A load calculation was required to determine the amount of electric power used in running a refrigerator. The heat load that must be removed consists of heat from the wall surface area of the insulation cooling box, number of fish inside the insulated cooling box, and the temperature difference between inside and outside the insulated cooling box and electrical load. The results showed that the insulation heat leak obtained was 1.95 Kcal/h, while the heat load from air change was 6.48 Kcal/h. The amount of fish that can be stored in the refrigerator was 300 kg, so the heat load obtained was 68.75 Kcal/h. The total heat load of the refrigerator was 77.20 Kcal/h. Consider refrigerator heat load, and estimation electrical charge were 220 Watt, the total heat load for the cooling box was 310
Watt. The generator of 1.000 Watt set was chosen to cover the electrical power requirements of the cooling box refrigerator and load calculation result is presented in Figure 2.

![Figure 2. Load calculation result](image)

LPG fuel consumption of generator was 0.8 kg per hour; thus, the requirement for 7 hours operations was 5.6 kg equivalent to 2 tubes of 3 kg LPG. The total operational cost needed for two tubes LPG was IDR 40.000 equal to IDR 133.33 every one fish. This cost is relatively low when compared to fish damage due to poor transportation and storage systems.

4. Conclusions
According to the limitations of post-harvest infrastructure in handling fish and seafood product, refrigerator system for cooling box on three wheels motorcycle to support transportation from fish port to market or consumers is required and applicable. LPG was chosen because it is more economically and profitable than gasoline with comparison was obtained respectively 40.71% lower than premium gasoline, 62.63% lower than pertamax gasoline, and 64.85% lower than pertamax plus gasoline. The calculation of refrigeration heat load was carried out by applying heat transfer theory. Since the refrigeration heat load was obtained 310 Watt, then the type and capacity of the generator were easily determined.

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