Plasma Technology in Cold Storage for Shelf Life Extension of Fresh Fish

Y Hartadi¹, M Nur¹,² and B Fajar¹,³

¹ Master of Energy, School of Postgraduate Studies, Diponegoro University, Semarang – Indonesia
² Science and Mathematics, Diponegoro University, Semarang - Indonesia
³ Mechanical Engineering, Diponegoro University, Semarang – Indonesia

eyusufhartadi@gmail.com

Abstract. Low temperature storage or cold storage to prevent bacteria and microorganisms from growing on food. Maintaining the quality of fresh fish when stored above freezing temperatures requires special treatment to maintain the quality and prolong the storage. The use of ozone as disinfectant could be a solution to the decreasing quality of fresh fish. The combination of ozone technology with cold storage gives a great advantage in storing fish in fresh conditions. The use of ozone generating plasma technology in cold storage offers a space for increased energy efficiency and economic value by using three time less energy use intensity than cold storage without plasma technology, which means that the plasma technology in cold storage provides a three-fold benefit in terms of energy costs per kilogram of fresh fish per day. A prolonged shelf life as well as a decrease of energy use intensity is very important in food distribution chain, especially for fresh fish that are vulnerable to damage.

1. Introduction

The most expensive fishery products are fresh fish and the cheapest are canned and salted fish [1]. The main obstacle in the sale of fresh fish products is the limit in storage time so that they should be stored in a frozen condition [2]. In a fish distribution chain system, storage capacity affects the quality and display time for selling fish. Being able to preserve fish while maintaining their good quality, will further extend the economic value of the fish [3].

Storing fish in fresh condition has a certain time limit [4]. The price of fish is strongly influenced by the supply and demand of the market, so maintaining fish freshness for a longer period will increase its economic value [5]. Analysis of the dominant cost structure in the fish distribution chain shows the percentage of fish reaches 46.7% for non-freezers and 43.6% for freezers [6]. This study focuses on the analysis of power consumption in the application of plasma ozone generator technology in cold storage to increase the shelf life of fish.

The use of ozone generating plasma technology for disinfectants provides more space for energy efficiency and extends its shelf life to increase its economic value [7]. Energy consumption analysis was carried out to arrange the energy balance as a basis for determining further analysis [8]. The measurement of cold storage energy consumption in combination with plasma ozone generator technology to determine the amount of energy that can be saved [9].
2. Methods

Analysis of the cooling load is done by calculating the refrigeration load, which is a calculation to determine the power required by the evaporator. Refrigeration load is affected by:

1) Product load is the refrigeration load to reduce the temperature of fish products, is directly proportional to the mass, sensible heat and temperature gradient of the fish when load into cold storage [10],

\[ Q = m \times C_p \times \Delta T \]  

2) Transmission heat load is caused by the heat loss of the cold storage casing relative to the surrounding environment, namely the top, bottom, right, left, front and rear partitions [11].

\[ Q_{wall} = \frac{A \times (\Delta T)}{\frac{1}{h_a} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{h_b}} \]  

3) Infiltration load is caused by heat losses due to the flow of air in and out, and the activity of opening and closing the cold storage door [4].

4) Equipment load is the load caused by electrical devices in cold storage, namely lamps, exhaust fan, evaporator fan, condenser fan, and fans. The load of the lamps and fans can be determined from the power indicated on their nameplate [12].

The study used cold storage and D’Ozone generator owned by Teaching Industry, Universitas Diponegoro based on the following frame of thought:

![Figure 1. Route map of research](image-url)
Measurement was conducted to retrieve power consumption data on ozone generating plasma machine. After that, the temperature of the cold storage was measured from the ambient temperature of 27 °C to 2 – 8 °C. Power measurement based on door openings was conducted as the simulation of fish loading into the cold storage. The study focused on the analysis of cold storage performance loaded by fresh milkfish, equipped with HFA 134a refrigerant, then an analysis of its energy consumption was performed.

3. Result and Discussion

3.1. Ozone generator power consumption analysis
Plasma occurs when the electrical discharge energy from the electrode plate reaches a condition equivalent to the ionization energy of a gas in the dielectric chamber [13]. Ionization results in the formation of ozone gas [14]. Power consumption of 0.151 kWh produced ozone dissolved in fish water at a concentration of 2 ppm for 60 minutes. In the initial minutes the power consumption looks greater because the electrode condition was still cold and some energy was consumed to reach the ionization stage. Then in minute 20, it reaches a stable condition, where fluctuations are regular and thermal equilibrium was reached at the electrode plates and the air flow in the space between those plates. Observed fluctuations were affected by the voltage of the source of electricity.

3.2. Theoretical cooling load computation
The computation of theoretical cooling load includes all loads in cold storage operations, namely:

1. Cooling load is the result of milkfish having a total weight at 3 tons, sensible heat (Cp) at 0.78 kcal/Kg, and temperature before loaded into cold storage was 27 °C. The results of the milkfish mass multiplied by its sensible heat and the difference in temperature resulted in a heat load of 68.04 kWh or 92% from total load. Preserving milkfish in cold storage with ozone treatment and non-ozone treatment shows a similar result of the product's heat load.

2. Transmission heat load or body load is affected by heat loss in cold storage casing across the entire surface. Cold storage insulation system consists of three layers, namely 2 mm thick SUS304 stainless steel plate, 8 mm thick polyurethane foam and the inner layer is 2 mm thick SUS304 stainless steel plate. Heat transfer coefficient of SUS304 is 16.2 W/m²°C and polyurethane foam is 0.026 W/m²°C. Total area of cold storage casing is 23 m² with inside temperature of 5 °C and the ambient temperature of 28 °C, so, the result of the calculation shows that transmission heat load was 0.151 kWh or 5% of the product’s total load.

3. Equipment load is the load of electronic equipment in the cold storage, that is lamp (25 watt), exhaust fan (36 watt), evaporator fan (45 watt) and condenser fan (45 watt) results in a total equipment load at 0.146 kWh or 3% from total load

4. The infiltration load is the heat loss that occurs due to the activity of opening and closing the door when loading and unloading the fish. The load is the biggest compared to other loads, because it increases the temperature of the cold storage space relatively fast.

3.3. Cold storage power consumption
Cold storage was set at the temperature 2-8 °C and consumed power of 0.885 kWh. The measurements show the average ambient temperature outside the cold storage was 29 °C and the average temperature inside the cold storage was 27 °C. The results of measurements without product load suggests that a temperature decrease in cold room storage temperatures needed 1,8 minutes while a 1 °C increase needed 4,6 minutes.
3.4. **Power consumption on ozone treatment**
Simulation of fish storage with ozone treatment by inserting 3 tons of milkfish, having ambient temperature of 29 °C and cold storage room temperature at 27 °C. Cold storage turned on and reached constant room temperature 2 °C in 4810 minutes or 200 hours. Cooling load included product load measured at 68.036 kWh, equipment load at 3.504 kWh per 24 hours, body load measured at 3.624 kWh per 24 hours and plasma power load at 0.3 kWh per 24 hours.

On day 5 and 10, a simulation on unloading 1 tons of fish was conducted for 30 minutes. During the door opening, the room temperature rose up to 24 °C. Time measurement was conducted during the operation of compressor, showing 448 minutes for 6.608 kWh power consumption.

On day 6, 7, 8, 9, 11, 12, 13, 14, in average, the compressor was operated for 398 minutes consuming an average power of 171 kWh.

On day 15, the power consumption was 6.021 kWh because the ozone treatment was conducted once in 24 hours. Storing fish in cold storage with ozone treatment for 15 days required compressor to be activated for 9,329 minutes or 155.489 hours resulting in total power consumption of 140.443 kWh.

3.5. **Power consumption on non-ozone treatment**
Simulation of storing fish on non-ozone treatment was conducted by loading 1 tons of milkfish, having ambient temperature at 29°C and cold storage room temperature at 28°C. Cold storage was activated and reached constant temperature at 2°C in 1,538 minutes or 26 hours. Cooling load included product load at 22.68kWh, equipment load at 3.504 kWh per 24 hours and body load at 3.624 kWh for 24 hours.

On day 5 and 10, 1 tons of fish were unloaded and fresh fish having body temperature of 27°C were loaded, requiring 60 minutes. During the door opening, the room temperature increased to 26°C. The door was closed and compressor was activated to obtain a constant temperature of 2°C, requiring 1,538 minutes or 25.6 hours consuming 24.120 kWh of power. On day 6, 7, 8, 9, 11, 12, 13, 14 and 1, in average, compressor was activated for 398 minutes, requiring average power of 5.871 kWh. Storing fish in non-ozone cold storage for 15 days required compressor to be activated for 9,389 minutes or 156.481 hours, consuming an aggregate power of 142.806 kWh.

3.6. **Discussion**
The use of ozone generating plasma technology in cold storage shows increased efficiency in power consumption as well as prolonged shelf life. The measurement shows that the power consumption of cold storage for milkfish for 15 days decreased from 142,806 kWh to 140,443 kWh or 1.65%. The energy use intensity for non-ozone fresh fish treatment was 0.0095 kWh/Kg and after ozone treatment, the intensity decreased to 0.0031 kWh per kilogram of fresh fish. It shows a positive outcome to be further developed in the industry of fresh fish storage.

4. **Conclusion**
Based on the study, plasma cold storage has been more efficient, more durable, and has the potential to be used in fresh fish distribution systems more efficiently. Research on the implementation of ozone generating plasma technology would be beneficial, especially for its usage in fishing vessels and fish distribution using renewable energy sources.

**References**

[1] Abidin Z, Harahab N and Asmarawati L 2017 Pemasaran Hasil Perikanan Malang: UB Press

[2] Afrianto E and Liviawaty E 2011 Pengawetan dan Pengolahan Ikan Yogyakarta: Kanisius

[3] Park s.-l., Moon j.-D, Lee S.-H and Shin S.-Y 2006 Effective Ozone Generation Utilizing A Meshed-Plate Electrode In A Dielectric-Barries Discharge Type Ozone Generator
Elsevier Ltd.

[4] Kolbe E, Kramer D and Junker J 2006 Planning Seafood Cold Storage Alaska: Alaska Sea Grant College Program, University of Alaska Fairbanks

[5] BAPPENAS 2016 Laporan Akhir Prakarsa Strategis Optimalisasi Pemanfaatan Potensi Kelautan Menuju Terwujudnya Indonesia Sebagai Poros Maritim Jakarta: BAPPENAS

[6] Larasati M, Guritno A D, Kristanti N E and Suwondo E 2016 Analysis of Logistics Cost Structure of Fish Cold Supply Chain in Java Island AIP Publishing.

[7] Du Y and Ding Y 2016 Optimization of cold storage efficiency in Rankine - cycle - based cold energy storage system (Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA)

[8] K. Perindustrian 2011 Pedoman Teknis Audit Energi dalam Implementasi Konservasi Energi dan Pengurangan Emisi CO (Jakarta: PPIHLH & BPKIM)

[9] Zahar I 2018 Kajian Penerapan Ozon dari Generator Plasma Lucutan Berpenghalang Dielektrik dalam Ruang Penyimpanan Digin untuk Ikan (Semarang)

[10] Stoecker W F 1998 Industrial Refrigeration Handbook

[11] Cengel Y A and Boles M A 2005 Thermodynamics: An Engineering Approach, 5th edition

[12] Kolbe E and Kramer D 1993 Planning Seafood Cold Storage (Alaska: University of Alaska Fairbanks)

[13] Nur M 2011 Fisika Plasma dan Aplikasinya (Semarang: Undip Press)

[14] O'Donnell C, Tiwar B, Cullen P J and Rice R G 2012 Ozone in Food Processing (Iowa: A John Wiley & Sons, Ltd.)