Eutectic potassium chloride (KCl) solution as phase change material (PCM) for fish cold storage

R K Sukoco¹, Y S Indartono¹,², D Mujahidin³

¹ Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Jl. Ganesha no. 10, Bandung 40132, Indonesia
² Research Centre on New and Renewable Energy, Bandung Institute of Technology, Jl. Ganesha no. 10, Bandung, 40132, Indonesia
³ Faculty of Mathematics and Natural Science, Bandung Institute of Technology, Jl. Ganesha no. 10, Bandung 40132, Indonesia

*kristianto.sukoco@gmail.com

Abstract. Traditional fishermen need to buy ice blocks every time they go fishing, thus impacting their expenses. To potentially save money, an alternative solution using phase change material (PCM) is proposed. PCM contained properly is reusable, thus reducing expenses for fishermen. Eutectic potassium Chloride (KCl) solution is utilized as PCM, which has melting temperature of −10.7 °C and heat of fusion of 253 kJ/kg. The PCM is used to substitute ice as the currently primary source to chill fish in storage. The solution is contained in an aluminium-foil zip-lock bags, each containing 670 grams of solution. The experiment uses two Polystyrene boxes, one containing 10 pouches of eutectic KCl solutions as PCM and the other containing ice cubes with the same mass. Two kg of fish is stored for 24 hours in each box. Thermal analysis shows that the box temperature containing KCl solution is steady for the 24 hours of experiment. Starting to be steady at −2.8 °C from room temperature, the box temperature increases slowly, reaching only 2.1 °C after 24 hours. Organoleptic test shows that the fish stored inside KCl box loses 1.39 quality points on average, compared to 1.89 in ice box after 24 hours. Therefore, the fish in the PCM box is slightly fresher than the one stored using ice cubes.

1. Introduction

Indonesia has a big potential in the fisheries sector. In fact, fisheries product is one of the primary export commodities of Indonesia. Indonesia produce around 11.5 million tons of fisheries commodities in 2016, 6.5 million tons of which are harvested fresh fish. Moreover, in 2017, Indonesia is the 9th largest country in terms of fisheries export value, amounting to $4.2 million of total exports [1].

Indonesia has 2.5 to 3.3 million people employed as fishers, with around additional 1 million work in fisheries processing and marketing. However, around 90-95% of fishers are small-scale fishers, who use fishing vessels with less than 10 GT (gross ton) power [2]. Motorized vessels are only 32% of all fishing vessels, with the rest are outboard-motor boats at 41% and still 27% with no motors.

These vessels used by traditional fishermen therefore have no refrigeration or freezing machines. Commonly, ice blocks, which are usually shattered to small pieces, are used to chill fish until they arrive onshore. Due to ice blocks need to be refilled every time they go fishing, their expenses in ice to chill fish becomes significant. Moreover, for fishermen in remote areas such as Karimunjawa island, oftentimes they need to go outside of the island to buy ice blocks, making their expenses much higher.
Phase Change Materials (PCM) are substances that are utilized to store and release heat using their latent heat transfer at their phase-change stage. Due to PCM’s high heat of fusion, it is used widely as heat storage medium. Moreover, its phase-change stage often happens in steady temperature, thus making it able to stabilize temperatures.

The melting point of PCM is crucial point of considerations in choosing PCM and the configuration of PCM inside the cool box. Eutectic potassium chloride solution was used as phase change material for fish storage. Eutectic salt-water solutions are known for their high heat of fusion, subzero melting temperature, the presence of subcooling phenomena, and its problem with phase segregation. However, the segregation could be minimized significantly if the mixture is eutectic [3]. This is rather important to reduce the drop of cold storage performance and the reusability of the PCM as cold storage medium. Potassium Chloride (KCl) solution with 19.5% (wt.%) mixture is a kind of eutectics inorganic PCM. KCl eutectic solution has a melting point of −10.7 °C and high heat of fusion of 253 kJ/kg [4]. Its low melting temperature could be utilized to store perishable foods such as fish. PCMs usually need to be encapsulated or contained properly to prevent contamination to products or the environment. If contained properly, KCl eutectic solution then has the potential to be used as PCM to store fish. Therefore, with its ability to be reused or recharged, KCl eutectic solution could be a solution for fish storage.

2. Related Works

Gin and Farid [5] explored the use of PCM for ice cream and meat storage. They used a vertical freezer with 153-liter volume, controlled at −16 °C, and was equipped with PCM panels on its inner walls. Eutectic ammonium chloride-water solution PCM was utilized to hold the temperature inside the freezer, while the power was turned off for 2 to 3 hours. The freezer equipped with PCM panels had the temperature significantly slower. After 2 hours of power-off, the temperature is still below −10 °C, compared to −2 °C in the original freezer.

Ahmed et. al. [6] explored the area of transportation as the target for PCM utilization. They built two simulators of refrigerated truck trailers using polyurethane, sandwiched to aluminum panels and glass boards. One was equipped with copper wires which was filled with PCM, and the other was not filled with PCM. The temperature was controlled to 4 °C, and the heat flux to the inner walls was measured. They found that the simulator with PCM has 16.3% lower incoming heat flow compared to the other, on 24-hour average. This could be a method to save energy and reduce pollution from refrigerated trucks utilizing fossil fuels.

Johnston et. al. [7] developed an advanced technique to nano-encapsulate PCM for food storage. They use a method and technique to build a nano-structured calcium silicate (NCS) as a dry powder and an organic PCM, with 8 °C melting point. They use this PCM to store asparagus inside a box by cooling the box to 1-2 °C then put it on ambient temperature. The inner temperature of box containing reached 10 °C almost 6 hours longer than without using PCM.

Temperature is one of the most important parameters in keeping fish freshness and safety. Agustini et. al. [8] analyzed the effect of storage temperature for yellowfin tuna (Thunnus albacares) to the K-Value of the fish. K-Value is a well-known biochemical method in measuring fish freshness. K value is the ratio of inosine (Ino) and hypoxanthine (Hx) to the quantity of ATP-related compounds such as ATP (adenosine triphosphate), ADP (adenosine diphosphate), AMP (adenosine monophosphate), and IMP (inosine monophosphate) [9]. K-Value of 20% is considered to be sashimi grade and 50% is the limit of shelf-life expiration [9-10]. They found that storage temperature correlates strongly to the reaction rate to increase K-value. K-value of 30% was attained after 3.85 days, 7.2 days, and 15.5 days for fish stored at 5 °C, 0 °C, and −3 °C, respectively. Therefore, small difference in temperature can affect the fish quality and shelf-life significantly.

Guizani et. al. [9] conducted similar experiment to Agustini et. al. to measure the effect of temperature to freshness of yellowfin tuna. They also measure histamine content in the fish, a substance that is associated with seafood poisoning. They concluded that storage in 20 °C will result in rapid loss of quality and safety of fish, while storage in 8 °C results in fish shelf-life to be around 6 to 8 days.
Chang et al. [10] analyzed the effect of temperature on the quality of sea bass, including its K-Value. The temperature ranges from −3 to 10 °C. K-Value of 50% was reached after 2, 3, 8, and 30 days, respectively for 10, 5, 0, and −3 °C. It was concluded that reaching 0 °C or below was crucial for keeping fish fresh and safe. Silva [11] measured the histamine formation in big eye tuna and skipjack at different storage temperature. The tuna reached toxic level of histamine (> 50mg/100g) rapidly, after only 1 day, if stored at room temperature of 22 °C. At refrigerated temperature, it reached toxic level after 3 and 6 days, for 10 and 4 °C, respectively. It also was found that skipjack has higher levels of histamine than big eye tuna at the same storage temperature.

Some institutions give a recommendation for fish storage temperature. FAO [12] gives 0 °C as the ideal storage temperature for chilled fish, although fish can also be stored in frozen temperature below −18 °C with different treatments. Traditional way of storing fish with ice, as FAO puts it, is favorable for both fish freshness and for practical considerations. FDA [13] gives 0 °C as the ideal storage temperature. The fish storage temperature should also not be higher than 4.4 °C (40 °F). FDA warns that higher storage temperature can result in food poisoning due to histamine formation.

3. Materials and Methods

3.1. Fish Samples
Pacific Chub Mackerel (Scomber japonicus) fish is used as the specimen for cold storage experiment using PCM. The fish were obtained from local traditional market in Cioroyom, Bandung, West Java in the morning. Fish were randomly separated and put into the box with equal mass.

3.2. Phase Change Materials

![Figure 1. PCM packaging using aluminum foil zip bags](image)

Eutectic potassium chloride solution has melting temperature of −10.7 °C and heat of fusion of 253 kJ/kg [4]. For the use of fish cold storage, the eutectic potassium chloride solution is suitable due to its subzero melting temperature, which compensates the thermal resistance from heat convection from the PCM to the surrounding air. Its high heat of fusion helps with the duration of the passive cold storage. Potassium chloride technical grade (99%) was used, mixed with distilled water with 19.5% (wt.%) mixture, which is its eutectic mixture [4]. The solutions were then contained inside an aluminum-foil zip-lock bags, as shown on Figure 1, where 670 grams of solution was contained in each bag. This packaging has the purpose to prevent contact between fish and the PCM. Moreover, the chosen container was proven to be tough enough to prevent any liquid leakages. Ice cubes, in the form of small cylinders, were obtained from local sellers.
3.3. Cold Storage Experimental Procedure
The objective of this cold storage experiment is to compare the thermal performance and the fish quality between the use of eutectic potassium chloride solution and ice cubes to store fish, which is commonly used by traditional fishermen to keep the fish fresh as it is delivered. To simulate real-life condition, two Polystyrene boxes, which have equal volume of 53 liters and equal dimensions, were used to store fish. One box contained eutectic potassium chloride solutions inside ten (10) pouches, thereby totaling 6.7 kg of PCM inside. The pouches were put around the inner walls of the Polystyrene box. The sketch is shown in Figure 2. The other box contained 6.7 kg of ice cubes, which is equal to the total mass of potassium chloride solutions inside the first box. The ice cubes were configured to be three layers, as shown in Figure 3, each has equal mass.

Each box contained two kilograms of fish inside. In the box with PCM, a thin aluminum container was placed to separate the pouches containing PCM and the fish stored inside. This was done to prevent any contamination to the fish products. The fish in this box were all put into this container forming around 3 to 4 layers. In the box containing ice cubes, the fish were configured into two layers, with each layer of fish was between two layers of ice cubes. The configuration of the Polystyrene box containing ice cubes is shown in Figure 3. Each layer of fish in this box has equal mass.

The potassium chloride solution and ice cubes were compared side-by-side at the same time. They were also taken out of the freezer into their respective boxes at the same time. After the PCM pouches were stored inside the freezer for around three days, then the pouches were put inside the Polystyrene box around its walls, as explained previously. Immediately, the fish were put into the aluminum box. At the same time, after ice cubes were taken out of the freezer, the ice cubes and fish in the other box were configured as explained. The experiment lasted for 24 hours. The duration was chosen in regards from the total duration from the fish harvesting to the fish delivery to market. This includes the fishing process by local fishermen, the duration from their onshore arrival up to delivering fish to the fish collectors, the duration of fish kept by fish collectors, and the duration to deliver fish to the market.
3.4. Temperature Measurement
Temperature inside the box and the PCM temperature itself are the most crucial parameters in evaluating cool box performance using PCM. Therefore, these two temperature points were measured for the box containing eutectic potassium chloride solution. The box temperature was measured at the center (vertically and horizontally) of the box. For PCM temperature, the temperature sensor was placed inside one of the pouches which contains PCM.

Inside the box containing small ice cubes, two temperature points were measured. These two temperature points were fish temperature which contacts directly to the ice cubes. The first and second temperature sensors each measured one fish temperature at the lower and upper fish layers. The temperature sensors were placed on the fish body. Additionally, ambient temperature from the environment nearby the cool box was measured. All these five temperatures were recorded every 5 seconds.

3.5. Organoleptic Test
Organoleptic test is one of the requirements to determine fish freshness, according to Indonesian Standard [10]. The test uses human sensory to measure fish quality. There are in total six parameters of the fish to measure in this test: appearances, where eye, gill, and slime qualities are measured, flesh, odor, and texture. The score for each parameter ranges from 1 to 9, with 1 being the worst and 9 the best. However, in each parameter, there is a guidance or description for the respective parameter. Hopefully, any subjectivity in fish quality measurement could be minimized.

Organoleptic test was done to compare fish quality before and after the experiment. One fish from each box was chosen randomly right before the experiment. Then, three people, with the authors not included, acted as evaluators or panels to measure fish quality for the organoleptic test. The evaluators will then fill an assessment sheet similar to the one in Indonesian standard for fish freshness, which is detailed in SNI 2729:2013 *Ikan Segar* [14] to measure fish quality based on six parameters. When the experiment is done, the fish quality was measured again by the evaluators by filling the same table. Additionally, to keep objectivity in the quality measurement, blind test method was employed in measuring fish freshness. All of the evaluators have no information as to which fish was stored inside the box containing eutectic KCl solutions, and which fish stored with ice cubes. The loss of quality, hence the difference of quality before and after the experiment is the main criteria to measure cold storage performance for fish.

4. Results and discussions
4.1. Temperature Data
The temperature data of fish storage experiment is shown in Figure 4. Temperature of the eutectic KCl solution inside the pouch (marked as “KCl Pouch”) starts at around −30 °C (not shown) and increasing rapidly due to the sensible heat absorbed by the PCM. After the first 4 hours, then the temperature became steady at around −11.5 °C, which is close to the melting point of the eutectic KCl eutectic solution, which is −10.7 °C [3]. At this point, the eutectic KCl solution begins to utilize its latent heat capability. It slowly melts at its phase-change temperature. The eutectic KCl solution has high latent heat, thus the temperature is able to be steady for around 14 hours. After that, the temperature increases, marking the end of phase-changing stage and the beginning of sensible heat absorption while in the liquid phase.

The box temperature that contains the eutectic KCl solution (marked as “KCl Box” in Figure 4) starts at room temperature and rapidly declines to −2.8 °C due to the presence of PCM, which had low temperature. Then, the temperature starts increasing but rather gradually. In fact, after 24 hours of cold storage experiment, the box temperature only reaches 2.1 °C, which is quite impressive, increasing only around 5 °C during the 24-hour interval. This happens due to eutectic KCl solution’s high latent heat and low melting point.

As discussed previously, the PCM temperature is steady after the 4th hour of storage. Therefore, the box temperature becomes even more steady after the 4th hour of storage, due to the utilization of PCM’s latent heat storage, hence holding the box temperature as well. The box temperature is also still aligned with some recommendations on chilled fish storage, which is around ice’s melting point (0 °C) and below 5 °C [7, 8].

![Figure 4. Temperature data from 24 hours of fish storage.](image)

The box temperature is even comparable to fish temperature stored in the ice box. As stated previously, there are two temperatures measured: fish temperature on lower and upper layers. These two temperatures are quite identical. They begin at around −30 °C (not shown) and increased rapidly, then it starts to be steady after the first 4 hours. As ice melts at 0 °C, the temperatures are steady at around −1 to 0 °C until the end of experiment. Therefore, the box temperature containing eutectic KCl solution, which is −2.8 to 2.1 °C is comparable to storage using ice cubes.
The main advantage of using PCM encapsulated in a container is that PCM as cold storage medium can be recharged, that is, it can be frozen again to be used for the next cooling occasions. On the other side, ice cubes will be melted and turn into water (liquid) after its use. Although the water could be yet frozen again, it doesn’t use any packaging, therefore difficult to be reused. The difficulty in obtaining ice cubes or ice blocks and the need to buy them every time fishers go fishing are two of the problems facing fishermen, hence increasing their operational cost. Alternatively, if the ice is contained in the same container as the one used for eutectic KCl solution, then storage temperature will not be as low as if eutectic KCl solution is used, which could affect fish quality. Therefore, thermally, the use of eutectic KCl solution with zip-locks of aluminum foil material could be an alternative solution to store fish for fishermen and fish cold-chain until it’s delivered to the customer.

4.2. Organoleptic Test Result
The result of organoleptic test on fish stored in both boxes is shown in Table 1. The data shown are each averaged from the scores submitted by the 3 evaluators. As shown, on average, there is minuscule difference on the initial condition of fish stored in PCM box (8.72) and the one stored inside ice box (8.89). The parameters mostly have score of 9, and the lowest score is 8.33. The initial condition of both fish is therefore very fresh.

After 24 hours of storage, the fish stored in PCM box loses on average 1.39 points of quality, meanwhile fish stored in ice box lose 1.83. There is a little difference on the loss of average quality, indicating that the fish stored inside the box containing eutectic solution is slightly fresher, but not much, by only 0.44 points.

| Parameter | Fish in PCM box | Fish in ice box |
|-----------|----------------|----------------|
| Before    | After | Diff. | Before | After | Diff. |
| Eye       | 8.33  | 6.33  | 2.00   | 8.67  | 6.67  | 2.00  |
| Gill      | 8.67  | 7.00  | 1.67   | 9.00  | 7.67  | 1.33  |
| Slime     | 9.00  | 8.00  | 1.00   | 9.00  | 8.00  | 1.00  |
| Flesh     | 8.67  | 7.00  | 1.67   | 8.67  | 6.00  | 2.67  |
| Odor      | 8.67  | 7.67  | 1.00   | 9.00  | 8.00  | 1.00  |
| Texture   | 9.00  | 8.00  | 1.00   | 9.00  | 6.00  | 3.00  |
| Average   | 8.72  | 7.33  | 1.39   | 8.89  | 7.06  | 1.83  |

From Table 1, on the eye parameter, both fish lose 2 quality points, which is quite significant. However, there is no noticeable difference of the loss between the two fish. Both scored slightly below 7, which could be the eye qualities start to be stale. On the gill parameter, fish stored in PCM box loses 1.67 points, compared to the one stored in ice box with 1.33. The difference is minuscule, as both gills still show freshness. The gill parameter on both fish still score equal to or higher than 7.

Both fish contained in PCM box and ice box have good score in body slime, both still scoring 8 point after 24 hours of storage. The same score is also seen on the fish odor. Both fish have no noticeable difference in fish odor after the storage. From these parameters, the fish are still considered fresh.

Flesh quality score from fish stored in the box containing eutectic solution decreases 1.67 points into 7.00. Therefore, there is a noticeable difference after the storage. The flesh becomes slightly darker and its tissue is less strong. However, a bigger difference in flesh quality is from fish stored in ice box. The flesh quality score decreases 2.67 points into 6.00, even though they start at the same flesh quality.

In the texture parameter, fish stored in the box containing ice cubes undergoes a significant drop, from 9.00 to 6.00, which can be categorized as not fresh anymore. The fish texture becomes a bit tender, although if pushed by finger, the mark remains only for a while. Its initial condition is 9.00, which is dense, compact, and elastic. This is quite different from the fish stored inside PCM box. It only
undergoes 1.00 point of loss in texture. The texture is still dense and compact, although not as elastic as the initial texture. This 3.00 points loss on fish inside ice box could happen due to its exposure to water, after some of the ice melts. Initially, when it is tested for organoleptic before experiment, the fish is sliced a bit on its body. Therefore, exposure with water could affect its texture and flesh quality.

In the end, on average from the six quality parameters, the fish stored inside the box containing eutectic solution with the container is a little bit fresher than the one stored inside the box containing ice cubes. Although the difference is not significant, there are some parameters in which the one contained in the first box are significantly better than the one in ice cubes. Looking at the organoleptic result, eutectic potassium chloride solution with proper container is able to keep fish still fresh with the loss of quality is slightly lower than the one stored in ice cubes. The average of quality loses slightly less, the quality in some parameters lose significantly less, and the main advantage of PCM with containers, that is its reusability for the next fish harvests, remains.

4.3. Practicality Aspect

This research gives conclusion that eutectic potassium chloride solution, contained in a zip-lock bags with aluminum foil material, can be an alternative solution for traditional fishermen. They could save more money by reducing their operational cost from buying ice repeatedly and keep their fish quality better. The thermal performance shows that the PCM box could be comparable to using ice to store fish. Moreover, the organoleptic test shows that on average, the fish stored in the PCM box loses less quality compared to the one stored in ice cubes. Moreover, potassium chloride is regarded Generally Recognized as Safe (GRAS) by FDA, and that “…the ingredient is used in food with no limitation other than current good manufacturing process.” [15]. Therefore, any leakages will not make fish toxic.

However, the practice of traditional fishing should also be taken into account when considering alternative solutions like this. Shattered ice blocks and ice cubes are commonly used by fishermen to store their fish to keep fish fresh. For smaller-scale fishers, ice cubes are even commonly used. They are used to handle fish and ice in a certain method, which has been done for generations. Handling PCM inside zip-lock bags, however, is quite different. After using ice, the water is then thrown away and they will buy more ice. As opposed to that, if PCM inside pouches to be used, then it has to be stored inside a freezer for several days (depends on the size of freezers) to make it available again. Therefore, the availability of freezers along the cold chain should also be considered, especially for fishermen in remote areas. Moreover, the fishermen handle ice (e.g., for moving ice from one box to another) quite harshly, and there will be an impact load to the ice. Due to its hardness, the ice usually doesn’t break, and even if it does, then it still can be used. This kind of method cannot be used to handle PCM pouches. Even if the container used is stronger (e.g., thicker aluminum or steel containers), there could be a leakage on the container and contamination to fish will occur. The PCMs will then be replaced, hence more cost is spent.

Environmental aspect is one concern when utilizing any chemicals for public use or common practices, including fishing sector. The PCM, which is a 19.5% KCl salt-solution, needs to be disposed and replaced with new KCl solution after certain cycles of usage. Although the potassium chloride itself is considered safe to use according to FDA [15], the disposal of the solution in huge amount could be dangerous to the environment. Due to its target use for traditional fishermen and fish collectors, the disposal of KCl solution (after its implementation) will likely occur as part of domestic/household waste. Therefore, a chemical assessment to the KCl solution should be done prior to its implementation to meet the quality standard of domestic wastewater in Indonesia. The quality standard is regulated in a decree by the Ministry of Environment and Forestry of Indonesia [16]. The pH, BOD, COD, TSS, fat/oil content, Ammonia content, the total of coliform, and wastewater debit are regulated and have their own limits according to the decree. Due to its nature as salt solution, the pH will be the parameter that is altered the most from domestic tap water. Nevertheless, a full assessment of the KCl 19.5% solution should be conducted to minimize any risks to the environment.
5. Conclusion
Passive cold storage using eutectic potassium chloride solution as phase change material is therefore a viable alternative solution for short-term fish storage. The thermal performance shows that the PCM in the pouch is able to maintain box temperature below 5 °C, which is the recommended chilled storage temperature for fish, for longer than 24 hours. The box temperature is also steady, starting at −2.8 °C (once the phase-change stage starts) and increasing slowly to 2.1 °C after 24 hours of storage. The organoleptic test also shows that the fish stored using PCM loses quality lower than the one stored in ice cubes. Although the difference on average is small, there are some parameters in which the difference in quality loss between the two is significant. The PCM ability to keep fish freshness is therefore evident.

However, to implement this solution in real-life commercial case has some challenges, especially in traditional fisheries. Traditional fishermen often have their own methods to handle ice cubes as cold storage medium. Therefore, to implement this solution to traditional fisheries, some tests in commercial settings need to be done, and trainings should be conducted to those who will utilize it. The fishermen should be taught how to handle PCM pouches, or any other PCM containers, and the availability of suitable freezers need to be increased along the fish cold chain.

Acknowledgement
We gratefully acknowledge the funding from Riset Unggulan 2020 from Research Centre on New and Renewable Energy, Bandung Institute of Technology, Indonesia.

References
[1] Indonesia Eximbank Institute and UNIED 2019 Proyeksi Ekspor Berdasarkan Industri: Komoditas Unggulan (Jakarta: Indonesia Eximbank) (in Bahasa Indonesia)
[2] California Environmental Associates 2018 Trends in Marine Resources and Fisheries Management in Indonesia: A 2018 Review (San Francisco: California Environmental Associates)
[3] Mehling H and Cabeza L F 2008 Heat and cold storage with PCM: an up to date into basics and applications ed D Mewes and F Mayinger (Berlin, Heidelberg: Springer-Verlag)
[4] Li G, Hwang Y, Radermacher R, and Chun H 2013 Energy 51 1-17
[5] Gin B and Farid M M 2010 J. Food Eng. 100 372-6
[6] Ahmed M, Meade O, and Media M A 2010 Energy Conv. Mgmt. 51 383-92
[7] Johnston J H, Grindrod J E, Dodds M, and Schimitschek K 2008 Cur. Appl. Phys. 8 508-11
[8] Agustini T W, Suzuki T, Hagiwara T, Ishizaki S, Tanaka M, and Takai R 2001 Fisheries Sci. 67 306-13
[9] Guizani N, Al-Busaidy M A, Al-Belushi I M, Mothershaw A, and Rahman M S 2005 Food Res. Int. 38 215-22
[10] Chang K L B, Chang J, Shiau C, and Pan B S 1998 J. Agric. Food. Chem. 46 682-6
[11] Silva C C G, Ponte D J B D, and Dapkevicius M L N E 1998 J Food. Sci.63 644-7
[12] Food and Agriculture Organization of The United States (FAO) 2009 Code of Practice for Fish and Fishery Products (Rome: Food and Agriculture Organization)
[13] Food and Drug Administration 2019 Fish and Fishery Products Hazards and Controls Guidance Fourth Edition (White Oak: Food and Drug Administration)
[14] Badan Standardisasi Nasional 2013 Ikan Segar: SNI 2729:2013 (Jakarta: Badan Standardisasi Nasional) (in Bahasa Indonesia)
[15] 12 C.F.R (Code of Federal Regulations) part 184.1622
[16] Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor 68 Tahun 2016 Baku Mutu Air Limbah Domestik (in Bahasa Indonesia)