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Application of Inorganic – Organic Eutectic PCM (Phase Change Material) To Improve Coolbox Efficiency

Nanda Yuniarti[1], **Mifta Fatimah Supandi**[1], **Caecilia Pudjiastuti**[1], **Ketut Sumada**[1], **Stefano Ladini**[2], **Erwan Adi Saputro**[1]*

[1] Chemical Engineering, Universitas Pembangunan Nasional "Veteran" Jawa timur, 60294, **Indonesia**

[2] Energy Engineering, University of East Anglia, Norfolk, NR4 7TJ, **United Kingdom**

*erwanadi.tk@gmail.com

Abstract

The demand for efficient and environmentally friendly cold storage systems continues to increase, especially in the fisheries industry to maintain the quality of the catch. One alternative cooling medium is Phase Change Material (PCM), which is capable of storing and releasing energy in the form of latent heat during phase transitions. This study aims to evaluate the effectiveness of eutectic PCM composed of inorganic–organic materials in enhancing coolbox efficiency. The PCM was synthesized using food-grade ingredients: water, salt (NaCl), acetic acid, propylene glycol, and tapioca flour, and was then tested using Differential Scanning Calorimetry (DSC) and temperature profile analysis. Testing was conducted using various mass ratios of PCM to fish (from 1:1 to 4:1), and compared to conventional cooling media such as ice. The results showed that PCM with a 4:1 ratio was able to maintain temperatures in the range of -10°C to -0.4°C for 6 hours, with a total heat capacity of 1.4567 kJ/kg, significantly higher than that of ice (0.3120 kJ/kg). Furthermore, organoleptic tests indicated that fish stored with the 4:1 PCM remained fresh, scoring highest in aspects of odor, texture, and appearance. Therefore, the PCM developed in this study has proven to be more efficient in maintaining low temperatures and preserving fish quality compared to conventional cooling methods.

Keywords: PCM, Eutectic, Cooling, Coolbox, Energy Efficiency, and Fish Storage

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1. Introduction

The increase in the global population, which is estimated to reach 9.6 billion by 2050, brings major challenges to world food security, including in the fisheries sector[1]. The demand for fresh fishery products is increasing[2], along with increasing public awareness of the consumption of healthy animal protein[3]. However, one of the main problems in the distribution of marine catches is the decline in fish quality due to damage during the storage and transportation process[4]. This damage is largely caused by the inefficiency of conventional cooling systems such as ice cubes[5], which have limitations in maintaining cold temperatures consistently for long periods[6].

One of the innovative solutions that is developing is the use of Phase Change Material (PCM), which is a material that can absorb and release energy in the form of latent heat when a phase change occurs[7]. PCM has great potential as an efficient thermal energy storage medium because it is able to maintain temperatures in a relatively constant range[8]. In this study, an organic-organic eutectic-based PCM was developed from food-grade materials such as water, salt (NaCl), propylene glycol, acetic acid, and tapioca flour[9]. The mixture is designed to have a melting point that is in accordance with the storage temperature of fishery products and is safe for food products[10].

This study aims to examine the effectiveness of PCM in maintaining cold temperatures in coolboxes, compare its efficiency with ice cubes, and determine the most optimal PCM composition in storing cooling energy[11]. It is hoped that the results of this study can contribute to the development of more efficient[12] and environmentally friendly cold chain technology in the food industry, especially fisheries[13].

2. Methods

The PCM was prepared by mixing the ingredients in the following proportions: 415 mL of water, 60 g of NaCl, 25 g of tapioca starch, 27.5 mL of acetic acid, and 27.04 mL of propylene glycol. The mixture was stirred using a magnetic stirrer at 90°C and 500 rpm for 60 minutes until homogeneous. After cooling to room temperature (approximately 25°C), the mixture was packaged in ice pack containers for testing, as seen in **Figure 1**.

The testing was carried out by placing the PCM into a coolbox equipped with thermocouple sensors and a data logger to monitor temperature changes. The mass ratios between fish and PCM used in the experiment were 0:1, 1:1, 2:1, 3:1, and 4:1 (kg). In addition, a comparison was made between the use of PCM and conventional ice. Temperature monitoring was conducted over a period of 6 hours under open environmental conditions (ambient temperature of 25–30°C).

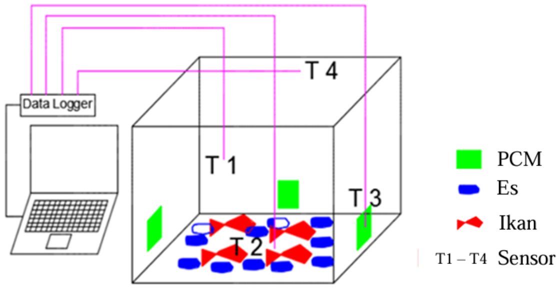

Figure 1. Experimental Setup

The charging process was carried out by freezing the PCM in a freezer at -19°C for 24 hours. Afterward, the PCM was transferred to the coolbox for testing during the discharging process, which involved melting at room temperature while recording temperature changes every 30 minutes using a data logger.

Subsequently, the cooling load (Q) was calculated based on the temperature changes and the heat capacity of the mixture, accounting for both sensible and latent heat. These data were used to evaluate the cooling efficiency of each PCM composition variation. In addition, thermal characterization of the PCM was conducted using a Differential Scanning Calorimetry (DSC) device to determine its melting point, specific heat capacity (Cp), and phase behavior during the solid–liquid transition process.

3.Results and Discussion

The PCM testing began with the charging process (in **Figure 2**), which involved freezing the PCM at -19°C for 24 hours. Measurement results showed that the PCM was able to reach a temperature of -10.7°C within 360 minutes. This value is lower than that of pure water, which only reached -9.5°C under the same conditions, indicating that the PCM formulation has a lower melting point and can therefore absorb more heat before melting.

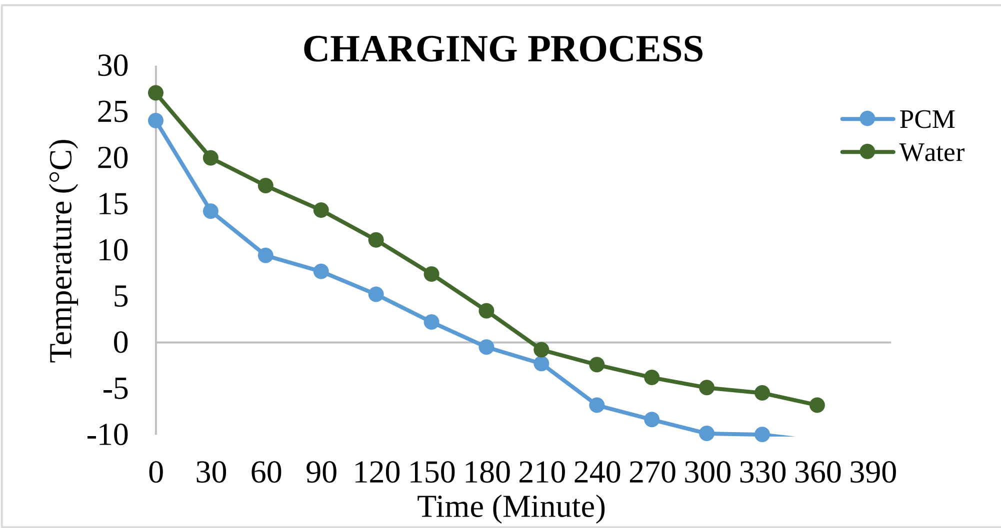

Figure 2. Temperature Profile Graph of Charging Process between water and PCM

The discharging process (in Figure 3-6) demonstrated that the PCM with a 4:1 ratio (PCM:fish) exhibited the most stable temperature range, maintaining between -10°C and -0,4°C for 6 hours. In contrast, the 0:1 ratio (without PCM) showed a more rapid temperature increase, rising from --1°C to 7.1°C over the same period. This indicates that PCM plays a significant role in slowing the rate of temperature increase within the coolbox.

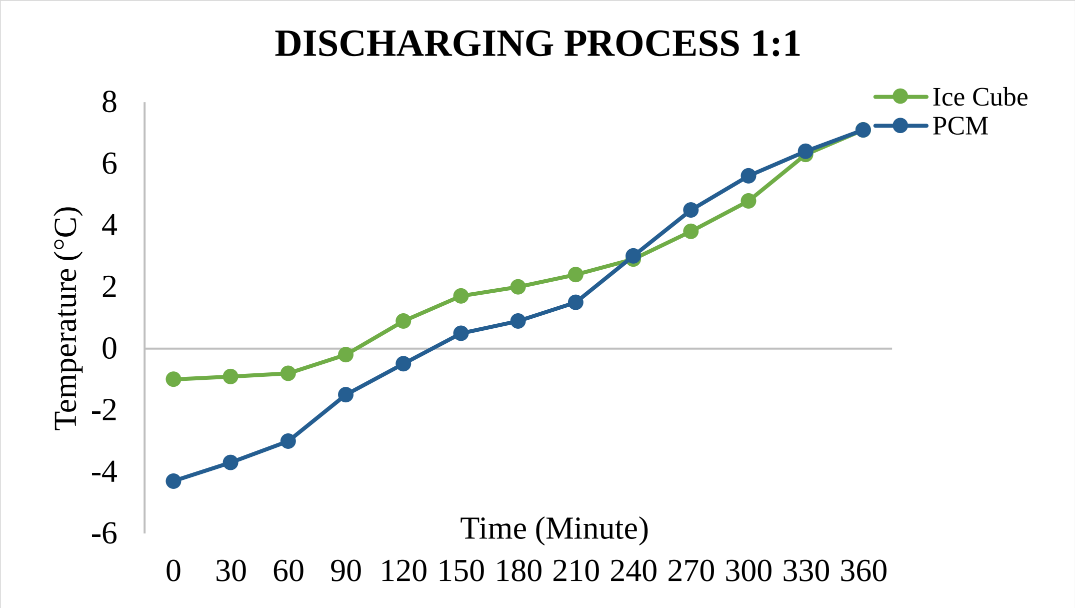

Figure 3. Temperature Profile Graph of Discharging Process PCM 1:1

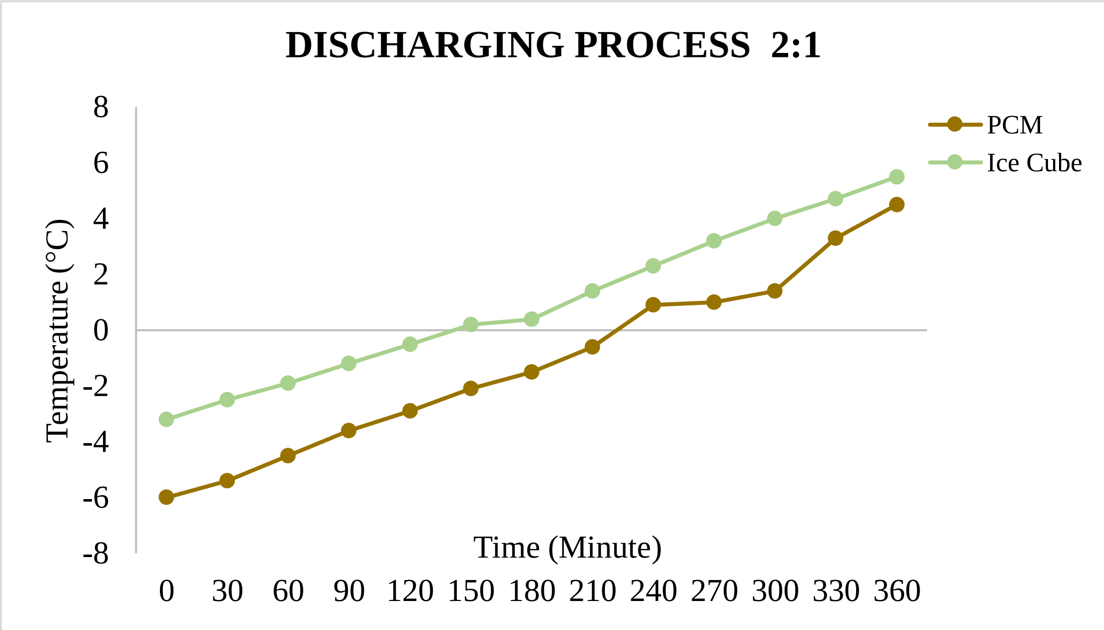

Figure 4. Temperature Profile Graph of Discharging Process PCM 2:1

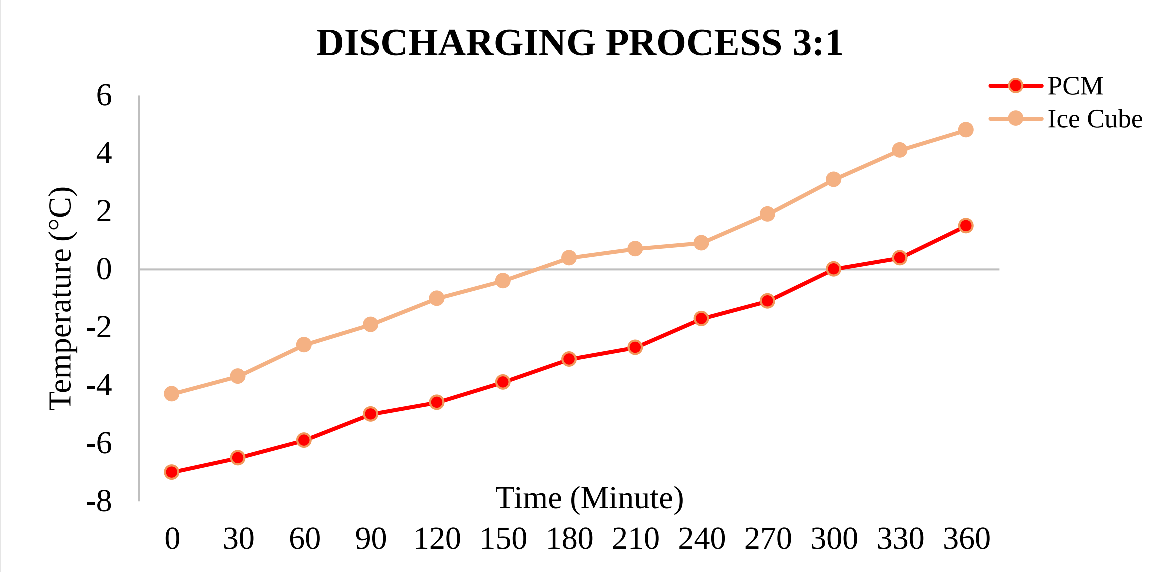

Figure 5. Temperature Profile Graph of Discharging Process PCM 3:1

Based on all the figures above, the data shows the results of the PCM discharging process. In several experiments, the lowest recorded temperature was -10°C, while the highest was 7.1°C. The experiment was carried out over 13 iterations, with data recorded every 30 minutes for a duration of 6 hours. Several comparisons were made between PCM and ice, with different sample ratios used in each test. In the first PCM sample, with a 1:1 (kg) ratio between PCM and fish, the temperature range observed was -4.3°C to 7.1°C. Next, in the third PCM sample with a 2:1 (kg) ratio of PCM to fish, the temperature ranged from -6°C to 4.5°C. In the sample with a 3:1 (kg) PCM-to-fish ratio, the temperature range was -7°C to 1.5°C. Finally, in the PCM sample with a 4:1 (kg) ratio of PCM to fish, the observed temperature range was -10°C to -0.4°C.

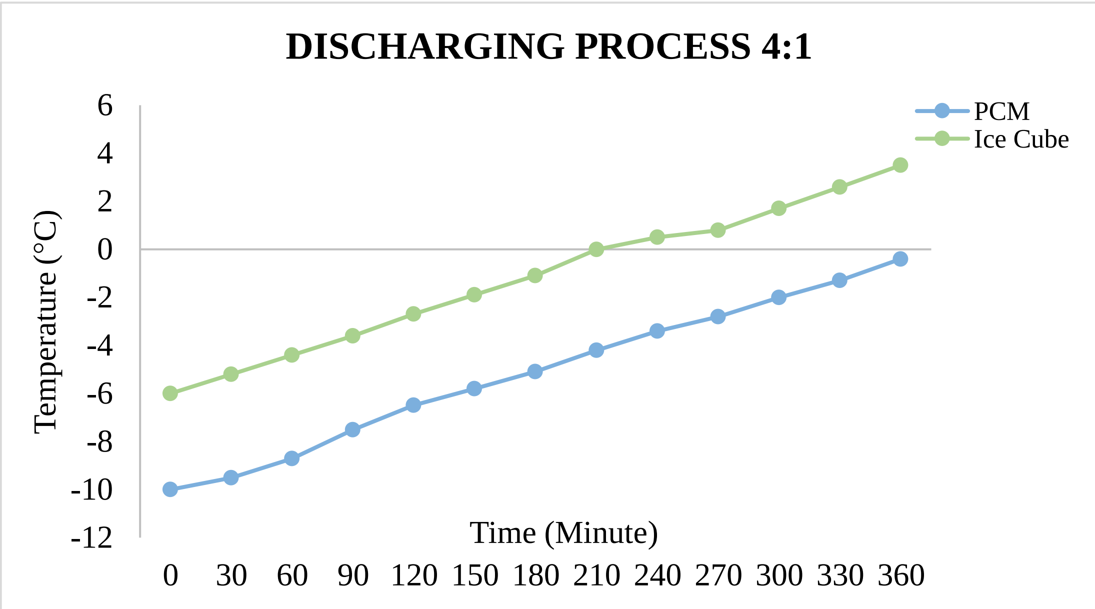

Figure 6. Temperature Profile Graph of Discharging Process PCM 3:1

The next comparison was conducted using only ice, without the use of PCM. In the first experiment, with a 1:1 (kg) ratio of ice to fish, the observed temperature range was -1°C to 7.1°C. In the 2:1 (kg) ratio of ice to fish, the temperature ranged from -3.2°C to 5.5°C. For the 3:1 (kg) ratio, the temperature ranged from -4.3°C to 4.8°C. Finally, in the last comparison using a 4:1 (kg) ratio of ice to fish, the recorded temperature range was -10°C to -0.4°C.

Table 1. Energy Consumption per PCM Sample

Sample	Sensible 1 °C	Sensible 2 °C	Q (Latent) kJ/kg	Q (Sensible) kJ/kg	Q total kJ/kg
Ice Cube 1:1	1,9	4,2	0,1666	0,0255	0,1921
PCM 1:1	4,8	5,6	0,3262	0,0411	0,3673
Ice Cube 2:1	3,4	5,1	0,1666	0,0711	0,2376
PCM 2:1	6,9	3,5	0,6524	0,0823	0,7347
Ice Cube 3:1	4,7	3,9	0,1666	0,1078	0,2744
PCM 3:1	7	1,1	0,9786	0,0961	1,0747
Ice Cube 4:1	6	2,7	0,1666	0,1455	0,3120
PCM 4:1	10	-0,4	1,3048	0,1519	1,4567
Without Ice Cube 1:1	5,5	5,7	0,0003	0,0443	0,0446
Without Ice Cube 4:1	3,6	6,6	0,0013	0,1613	0,1626

The total energy absorbed by the PCM during the discharging process showed that the sample with a 4:1 ratio had the highest total heat value of 1.4567 kJ/kg. This value is significantly higher compared to the coolbox without PCM, which only reached 0.3210 kJ/kg. The higher the total heat value, the greater the amount of energy the PCM can absorb and release, which translates to improved cooling efficiency[14].

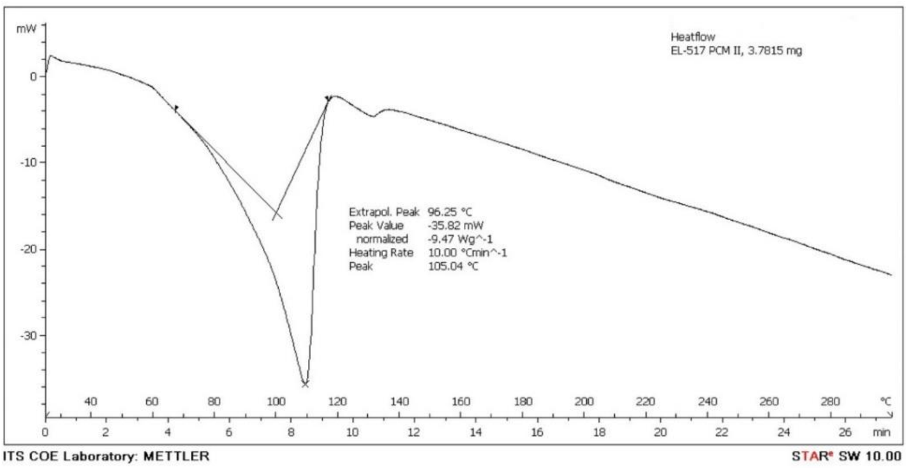

Figure 7. Analysis of DSC (Differential Scanning Calorimetry)

The performance of the PCM increased in line with the increase in PCM mass, providing greater energy absorption capacity. The 4:1 ratio offered an optimal combination of contact area, storage volume, and cooling duration. DSC analysis (in **Figure 7**) showed that the PCM began to melt at 95.25°C and completed the melting process at 105.04°C. The specific heat capacity (Cp) obtained was 9.47 J/g, which is higher than that of water (approximately 4.18 J/g). This indicates that the formulated PCM is capable of storing a larger amount of energy in the form of latent heat, which is essential for maintaining low temperatures over an extended period[15].

The use of PCM has been proven to maintain cold temperatures more consistently compared to ice. PCM not only sustains low temperatures but also ensures thermal stability without significant fluctuations. This is particularly important in the distribution of food products such as fish, which are highly sensitive to temperature changes[16].

4. Conclusion

The use of eutectic PCM composed of inorganic–organic materials has proven to enhance cooling efficiency in coolboxes. PCM with a 4:1 ratio maintained low temperatures (-10°C to -0.4°C) for up to 6 hours and showed higher total heat capacity compared to ice. Additionally, organoleptic tests indicated that fish remained fresher for a longer period. With superior thermal performance and food-grade composition, this PCM is a promising eco-friendly alternative for cold storage in the fisheries sector.

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Authors’ Declaration

Authors’ contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Competing interests - The authors declare no competing interest.

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