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Article

The Effect of Freezing Time on the Melting Time of Ice Blocks at PT Siantar Ice Factory

Calvin Klein Sitanggang[1,*], Tambos August Sianturi[2]
[1,2]Mechanical Engineering Study Program, HKBP Nomensen University, Pematangsiantar

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E-mail: *calvinsitanggang12@gmail.com*

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ABSTRACT

The background of this study is based on the needs of the ice block industry for products with higher resistance to melting in order to maintain distribution quality and improve operational efficiency. This research aims to analyze the effect of freezing duration on the melting time of ice blocks and to determine the most optimal freezing time among 24 hours, 27 hours, and 30 hours. The research methodology employs a mixed-method approach through direct observation conducted during Field Work Practice (PKL). Quantitative data were obtained from measurements of the melting time of ice blocks produced under three different freezing durations with three repetitions, while qualitative data were collected from observations of the freezing process and the physical condition of the ice. The freezing process was carried out at a temperature range of −10°C to −15°C using a brine-based cooling system. The results indicate that freezing for 24 hours produces an average melting time of 8.5 hours, freezing for 27 hours results in an average melting time of 10.2 hours, and freezing for 30 hours results in an average melting time of 12.5 hours. These findings demonstrate that longer freezing durations lead to increased melting time of ice blocks. Freezing for 30 hours provides the longest melting time and is considered the most optimal in enhancing resistance to melting. This study concludes that freezing duration has a significant effect on the melting time of ice blocks and can serve as a basis for determining more efficient and higher-quality ice production process standards.

1. Introduction

Freezing is one of the most widely used preservation methods to maintain the quality of perishable materials by inhibiting microbial activity and slowing down chemical reactions (Liu et al., 2020). The effectiveness of the freezing process is strongly influenced by freezing duration, which determines the physical properties and stability of the frozen product (Fatahillah et al., 2021). A longer freezing time generally produces a denser ice structure that enhances resistance to melting under ambient conditions (Giovanni et al., 2023).

The freezing process involves complex heat and mass transfer mechanisms that influence temperature distribution within the material during phase change (Pham, 2006). Heat and mass transfer models are essential to predict freezing time and optimize the efficiency of cooling systems (Delgado & Sun, 2001). Numerical simulations and heat transfer analysis show that temperature distribution during freezing significantly influences ice crystal formation and microstructural properties (Cheng et al., 2023).

The formation and size of ice crystals play a crucial role in determining the structural integrity and melting behavior of ice blocks (Kaale et al., 2011). Improper freezing conditions may lead to large and irregular ice crystals, which can reduce product quality and accelerate melting rates (Hu et al., 2022). Therefore, controlling the freezing process is essential to achieve optimal physical characteristics of ice.

Recent advancements in freezing technology have introduced numerical and computational approaches to better understand and optimize freezing and thawing processes (Fadiji et al., 2021). Numerical simulation methods can accurately model temperature distribution during freezing processes under different operating conditions (Yang et al., 2024). Furthermore, thermal energy storage systems based on phase change materials have been developed to improve cooling efficiency and reduce energy consumption (Ben Romdhane et al., 2020).

From an environmental and energy perspective, cold storage and refrigeration systems must be optimized to minimize energy usage and environmental impact (Zhu et al., 2023). The evaluation of energy efficiency in low-temperature refrigeration systems is therefore an important factor in determining overall system performance (Wang et al., 2025). Efficient thermal management not only improves freezing performance but also contributes to sustainable energy use by enhancing heat transfer effectiveness and reducing energy consumption in refrigeration processes (Selvnes et al., 2021).

The block ice industry is a crucial sector in the food supply chain, particularly in the Pematang Siantar region. PT Pabrik Es Siantar has been operating for decades, producing block ice used for cooling food and beverages and preserving seafood. In industrial practice, variations in freezing duration often occur due to operational conditions, which can affect the quality and melting resistance of the ice produced (Rihid, 2022).

In addition to industrial observations, several local studies have examined freezing processes and their practical applications in ice production systems (GUNAWAN, 2016). Cooling system performance has also been shown to influence the rate of ice formation and overall freezing efficiency (Yawara, 2012).

Based on these considerations, this study aims to analyze the effect of freezing time on melting time and the physical characteristics of ice blocks, with a focus on optimizing freezing performance and energy efficiency in ice production systems.

Figure 1. Water Reservoir

The water reservoir is a crucial component in the block ice production process, serving as a temporary storage area for clean water before it is used in the freezing process. The water stored in this reservoir comes from a clean water source that has undergone a filtering or pre-treatment process to ensure its quality meets ice production standards.

Water from the reservoir flows into the ice tray molds through a system of pipes or distribution channels. The filling process is carried out in a controlled manner to ensure each tray is filled with a uniform volume of water, resulting in consistent ice cubes in size and weight. Once the trays are filled, the trays are placed in a freezing tank (ice bath) to undergo a cooling process until the water freezes completely.

Figure 2. Closed Tray for Freezing Ice

The ice freezing area is a key part of the block ice production process, serving as the chamber where the phase change from water to ice occurs. This area typically consists of a freezing tank containing a cooling solution, such as brine, which serves as a medium for transferring cold from the refrigeration system to the ice molds.

The operating temperature in an ice freezer is typically between −10°C and −15°C, which is maintained consistently to ensure optimal freezing. Freezing time depends on system capacity, mold size, and operating temperature, but typically ranges from 24 to 30 hours for the ice cubes to form.

Figure 3. Ammonia Filling Valve

The ammonia fill valve is a component of the refrigeration system that serves as the inlet for ammonia refrigerant (NH_3) into the engine's cooling system. This valve is used during the initial filling, topping up, or adjusting the ammonia level in the system to ensure optimal cooling performance.

Figure 4. Circulation tube

The circulation tube is part of the refrigeration system, serving as a pathway and medium for the ammonia refrigerant to circulate during the process of generating cold temperatures, which are channeled into the ice freezing tank. This tube connects the main components of the cooling system, specifically the liquid receiver, expansion valve, and evaporator, which are located in or around the ice tank.

Figure 5. Ice Block Crane/Lifter

An ice crane, or ice lifter, is a mechanical device used to lift ice blocks from the freezing tank after the freezing process is complete. This tool simplifies and speeds up the process of removing ice molds from the ice tank, while reducing manual labor and improving operator safety.

At PT Es Siantar's block ice factory, the cranes used have a capacity of approximately 1,000 kg (1 ton). This capacity is considered safe and sufficient to lift a single mold frame containing several cans of ice at once.

Figure 6. Immersion in the ES Tank

Soaking in an ice bath is a crucial step in the ice cube production process, expediting the process of removing the ice from the molds before distribution to consumers. This process occurs after the ice cubes are removed from the freezing bath and before being removed from the ice cube trays. Soaking time generally ranges from 1 to 3 minutes, depending on the size of the mold and the temperature of the soaking water. The soaking water temperature is typically between 20°C and 30°C.

Figure 7. Ice block storage area

After the ice cubes have finished soaking in the soaking tub, they are sorted into an ice storage area. The ice storage area is an area or facility used to hold ice cubes that have been removed from the molds after the soaking process. This area serves as a temporary storage location before the ice cubes are distributed to consumers or transferred to the next stage of transportation.

Figure 8. Ice cubes

Block ice is the final product of the ice production process. It is a solid block produced by freezing clean water in a special mold. Block ice is widely used for various purposes, such as preserving fishery products, refrigerating food, and distributing and storing products that require low temperatures. The quality of the block ice significantly determines the quality of the final product, but in practice, freezing time is often determined solely by operational practices without adequate scientific analysis.

In fact, freezing time directly affects the structure of ice crystals; longer times tend to produce denser and more homogeneous crystals, ultimately slowing the melting rate. The lack of applied research on the appropriate freezing duration can lead to inconsistent product quality and potential energy waste. Based on field conditions at PT Pabrik ES Siantar, an issue is the inconsistent melting time of the ice product.

Based on this description, this research is focused on analyzing the effect of variations in freezing time on the melting time of block ice, with the aim of obtaining the most optimal freezing time to produce high-quality block ice and in accordance with industrial needs..

In order for the research to be more focused, the following problem limitations are set:

1. Time Variation: The tested freezing times were limited to 24 hours, 27 hours, and 30 hours.
2. The samples used were ice cubes produced by PT Pabrik Es Siantar with a total of 9 samples (3 variations with 3 repetitions).

The objectives of this research are:

1. Analyze the effect of freezing time on the melting time of ice cubes.
2. Determine the most optimal freezing time duration among the options of 24, 27, and 30 hours to improve the efficiency and quality of product distribution.
3. Providing recommendations for industry in determining the standards for the production process of higher quality ice blocks.

In addition to providing practical contributions to industry, this research was conducted within the framework of Field Work Practice (PKL), which serves as a bridge between academic theory and its application in the field. Through PKL, students are able to conduct real-world observations, analyze problems, and provide scientifically based recommendations for improving industrial efficiency.

2. Literature Review

Freezing is a widely used preservation method in industrial applications to maintain product quality by inhibiting microbial growth and slowing chemical reactions (Liu et al., 2020). In the context of ice block production, the freezing process plays a crucial role in determining the physical properties and durability of the final product.

The duration of freezing significantly affects the characteristics of ice. According to Fatahillah et al. (2021), longer freezing times allow more complete heat removal, resulting in a denser and more uniform ice structure. This condition directly influences the melting resistance of ice blocks, where denser ice requires more energy to undergo phase change.

From a thermodynamic perspective, the freezing process involves heat transfer mechanisms that control temperature distribution within the material. Delgado and Sun (2001) explain that heat transfer models are essential for predicting freezing time and optimizing refrigeration system performance. Efficient heat transfer leads to better control of ice formation and improved product consistency.

In addition, the formation and size of ice crystals are key factors affecting melting behavior. Kaale et al. (2011) state that smaller and more uniformly distributed ice crystals enhance structural integrity and slow down melting rates. Conversely, irregular and large crystals may create internal voids, reducing ice quality and accelerating melting.

Recent studies have also emphasized the role of advanced technologies in freezing processes. Numerical simulations and computational models are widely used to analyze temperature distribution and freezing characteristics under various operating conditions (Fadiji et al., 2021; Yang et al., 2024). These approaches provide more accurate predictions and support optimization of industrial freezing systems.

Furthermore, energy efficiency is an important consideration in refrigeration systems. Zhu et al. (2023) highlight that optimizing freezing conditions not only improves product quality but also reduces energy consumption and environmental impact. Therefore, determining the optimal freezing duration must consider both product performance and energy efficiency.

Based on these previous studies, it can be concluded that freezing time has a significant influence on the physical properties and melting resistance of ice blocks. However, variations in industrial practice often lead to inconsistent product quality. Therefore, this study focuses on analyzing the effect of freezing time on melting time to determine the most optimal condition for ice block production.

3. Research Methodology

This study uses a mixed-method approach that combines quantitative and qualitative data collection. Quantitative data were obtained from direct measurements of freezing duration and the melting time of ice blocks.

Qualitative data were obtained through direct observations of the physical characteristics of the ice blocks, including clarity, presence of air bubbles, and surface texture during and after the freezing process.

These qualitative observations were used to support the quantitative findings by providing additional insight into the internal structure and quality of the ice formed under different freezing durations.

3.1 Research Variables:

The independent variable is the freezing time (24, 27, and 30 hours), while the dependent variable is the melting time of the ice block (hours).

The research samples consisted of ice cubes produced with three different freezing times. Each variation was repeated three times, resulting in a total of nine ice cubes.

3.2 Data Collection Techniques and Procedures

Data collection was conducted by measuring the time required for ice blocks to completely melt under controlled environmental conditions. The melting test was carried out at an ambient temperature of approximately 27°C–30°C in an open room environment without direct sunlight exposure. Each ice block was placed on a flat surface at room conditions without forced airflow to ensure consistency during the testing process. Quantitative data were analyzed using a two-factor ANOVA test with replication and presented in tables and diagrams. Qualitative data were analyzed descriptively based on field observations. The researcher was directly involved in the production process during the internship. Supporting informants were machine operators and production supervisors. The research was conducted at the ice block industrial site for approximately one month.

4. Results and Discussion

Field observations indicate differences in ice block melting times due to differences in freezing times. The freezing times tested were 24 hours, 27 hours, and 30 hours.

Table 1. Freezing Time Against Melting Time

Date	Freezing Time	Repetition	Melting Time
09/15/2025	24 hours	1	8.3
09/16/2025		2	8.5
09/17/2025		3	8.7
09/19/2025	27 hours	1	10
09/22/2025		2	10.2
09/24/2025		3	10.4
09/26/2025	30 hours	1	12.3
09/29/2025		2	12.5
01/10/2025		3	12.7

Table 2. Anova Test: Two-Factor With Replication

Anova: Two-Factor With Replication			
SUMMARY	Pengulangan	Waktu Leleh	Total
24 jam			
Count	3	3	6
Sum	6	25.5	31.5
Average	2	8.5	5.25
Variance	1	0.04	13.091
27 jam			
Count	3	3	6
Sum	6	30.6	36.6
Average	2	10.2	6.1
Variance	1	0.04	20.588
30 jam			
Count	3	3	6
Sum	6	37.5	43.5
Average	2	12.5	7.25
Variance	1	0.04	33.491

Table 2. Summary ANOVA

Total		
Count	9	9
Sum	18	93.6
Average	2	10.4
Variance	0.75	3.0525

Table 3. ANOVA Comparison

ANOVA						
ırce of Variat	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	12.09	2	6.045	11.625	0.001556	3.885294
Columns	317.52	1	317.52	610.6154	1.17E-11	4.747225
Interaction	12.09	2	6.045	11.625	0.001556	3.885294
Within	6.24	12	0.52			
Total	347.94	17				

The ANOVA test data above shows that freezing time significantly influences the melting time of ice cubes. This is evidenced by the 0.05 > sample P-value of 0.001556.

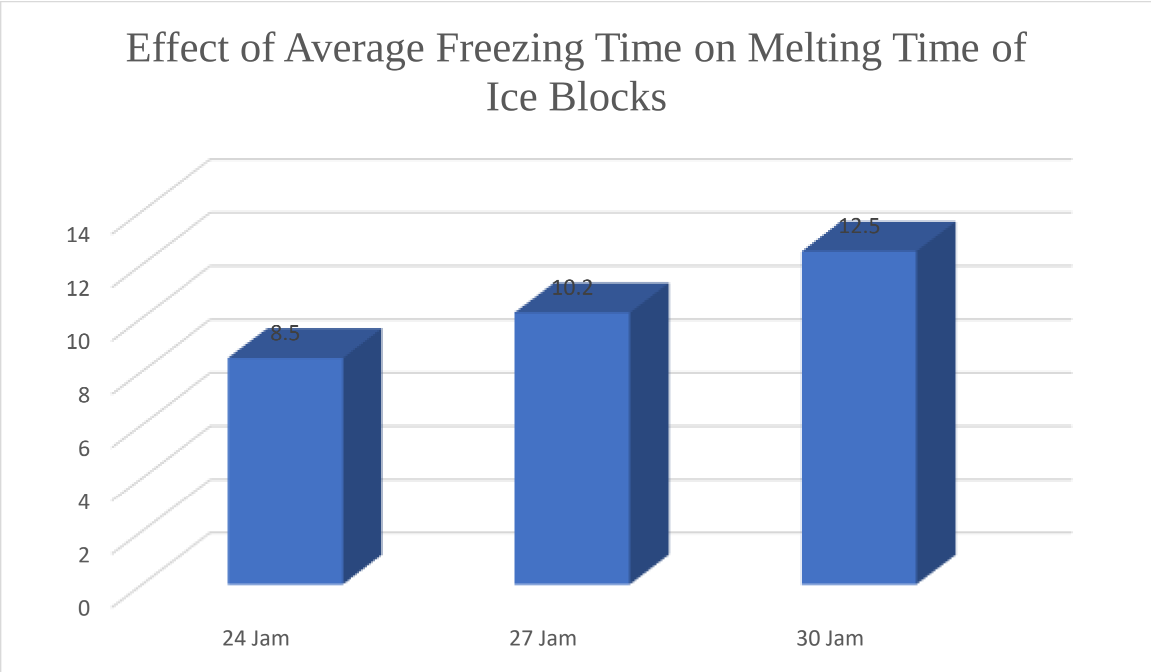

Figure 9. Effect of Freezing Time on Melting Time of Ice Blocks

Based on the observation data, a freezing time of 24 hours produces an average melting time of 8.5 hours. At a freezing time of 27 hours, the melting time increases to 10.2 hours, representing an increase of 1.7 hours compared to 24 hours. Furthermore, at a freezing time of 30 hours, the melting time increases to 12.5 hours, with an additional increase of 2.3 hours compared to 27 hours.

This trend indicates that longer freezing durations contribute to the formation of more uniform and compact ice crystal structures. During the freezing process, slower and longer heat transfer allows water molecules to arrange more systematically, thereby reducing the presence of air voids and internal imperfections within the ice.

As a result, the ice blocks require greater energy to undergo the phase change from solid to liquid, as described by the latent heat of fusion principle ($Q = mL$). This explains why ice formed over longer freezing durations exhibits longer melting times, not merely due to external conditions but also due to internal structural characteristics. Therefore, the relationship between freezing duration and melting time is not only based on experimental observations but is also supported by thermodynamic principles.

This shows that increasing freezing time has a positive impact on the melting time of block ice. Longer freezing times allow the ice to freeze more densely and completely, increasing its melting resistance.

The limitations of the study are acknowledged. The limited sample size and single location require further investigation into other factors, such as the influence of temperature, salt fluctuations, water pH, and other factors during freezing. The internship program also provides a hands-on learning approach. Students involved not only collect data but also understand the dynamics of the industry, adding value to their education.

5. Conclusion

Based on the analysis, it was concluded that freezing time has a significant influence on the durability of block ice at room temperature. Shorter freezing durations result in shorter melting times, while longer freezing durations increase the melting time of the ice blocks.

Although a freezing duration of 30 hours produces the longest melting time, it cannot be directly concluded as the most optimal condition in an industrial context. In industrial applications, longer freezing durations require higher energy consumption and increased operational costs. Therefore, extending the freezing time improves melting resistance but reduces energy efficiency. This indicates a trade-off between product quality (melting resistance) and energy efficiency, which must be considered in determining the optimal freezing duration.

While 30 hours provides the highest melting resistance, further analysis is required to determine the optimal freezing duration by balancing product quality and energy consumption.

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