Evaluation on the Potential Production of Horizontal Molding - Crystal Clear Ice Block Applying One Direction Heat Absorption

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Abstract. The paper presents investigation on a small capacity of horizontal molding-crystal ice block machine. The investigation was motivated by the increasing need for crystal clear ice blocks in Bali as a tourist destination. Therefore, it is necessary to develop a crystal block ice machine that is functional, practical and energy efficient. A lab size ice-block machine was developed. This ice machine applies a horizontal molding with heat absorption in one direction only which conducted by using a refrigeration system with R-404A. The heat absorption by the evaporator of the refrigeration system occurred only at the bottom surface of the ice-block molding. The machine constitutes two horizontal moldings with capacity of 125-150 kg ice per molding which is equivalent to a thickness of ice formation of 25-30 cm. The machine was designed to be able to accommodate refrigeration system of 1 kW and 2.4 kW cooling capacity. The production potential of the horizontal-molding crystal-clear ice-block machine with different cooling capacity was tested and evaluated. The evaluation included ice temperature, ice formation rate, ice production, time of production and energy consumption. The test results showed that the ice formation rate of the machine with 1 kW and 2.4 kW cooling capacity were relatively similar at the level of 10 cm ice depth in the first 24 hours and the formation rate decreasing for about 2 cm in the following 24 hours. It was found that time required to produce 2 crystal ice blocks of 125-150 kg was about 3 up to 4 days. The machine with 1 kW cooling capacity continually operated during the production period but the machine with 2.4 kW cooling capacity could operate with frequent cycling on and off. It is also found that the power consumption of the ice machine with lower cooling capacity consume 30% less energy than the machine with higher cooling capacity. This finding has also indicated that optimization on the cooling capacity and the application of secondary refrigerant may reduce the production time and energy use.

Keywords: Potential Production, Horizontal Molding, Crystal Clear Ice Block, Heat Absorption

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1 Introduction

In general, ice for tropical countries like Indonesia has very wide benefits. For example, to maintain the quality of fish caught by fishermen, ice cubes are a very vital need for fishermen. However, block ice is not recommended for consumption because the production process is less hygienic. Crystal ice with a more hygienic production process is an alternative for consumption, cooling drinks, fresh food and can also be mixed with juices. This has become one of the reasons many ice block factories have gone out of business due to shifting public interest in using crystal ice. As a result, sales of ice cubes have greatly decreased and production costs are no longer economical. Crystal ice has advantages over block ice: it is more hygienic, clearer and more practical. One of the attractions of the community is the level of clarity of ice. So that crystal clear ice is increasingly in demand.

Taking into account the energy consumption aspect, the ice-making process is an energy-intensive process and can result in high operational costs and factors causing a decrease in public interest in using block ice: (i) Block ice is unfit for consumption and unhygienic; (ii) Block ice is less clear; (iii) Blocked ice is not practical because of its large size, which can weigh up to 50 kg. Thus, the problems studied include: (1) How a thermodynamic simulation program can be developed that is capable of increasing the production feasibility of a block ice machine that is suitable for consumption, crystal clear and practical to use; (2) How can this simulation program be easily learned and used by lecturers, students and professionals to obtain a crystal block ice machine design that can later operate efficiently.

The aim of the research was to be able to develop a thermodynamic simulation in the form of an independent computer program for an energy-efficient crystal ice block machine so as to increase production feasibility and increase energy efficiency with crystal clear ice block product quality, practical use and suitable for consumption. Design innovation using this simulation program indirectly through the efficient use of electrical energy from the resulting machine products can also significantly reduce environmental impacts.

Based on reference searches, the technical aspects of a crystal block ice machine that can be produced by a thermodynamic simulation can meet the TTG (Appropriate Technology) criteria because it is easy to make, economically affordable, in terms of safety aspects it is safe to use and does not interfere with occupational health, is environmentally friendly, energy efficient and in accordance with the progress of the times [1]. The crystal block ice machine also has an output with identification of effective, comfortable, safe, healthy, efficient and productive [2-4].

The cooling process in the food chain, consumes quite a lot of energy. For refrigerated warehouse facilities, for example, 60-70% of the electricity used is for the refrigeration system [5,6] examines the potential for sustainable cooling technology to reduce energy consumption in food refrigeration. Their study focused on systems: tri-generation, air cycle refrigeration systems, absorption refrigeration systems, thermoelectric, Stirling cycle, thermoacoustic and magnetic refrigeration. The characteristics and potential applications of the system are also identified. Optimization of food storage systems to improve energy performance was also reported by Kozak et al. [7] who experimentally and theoretically studied food storage systems using phase change materials (PCM). Such a system is reported to be able to maintain a more stable product temperature because it utilizes latent heat from PCM. Oró et al. [8] also reported that the application of PCM in cold storage can reduce CO2 emissions in the range between 5% and 22%. Sustainable technology by applying a CO2 secondary refrigerant cooled by an ammonia refrigeration system in a refrigerated warehouse application has been published by Emerson Climate Technologies [9]. The applied sustainable refrigeration technology is completely free of HFC (hydro-fluoro carbon) refrigerants. HFC refrigerants have the potential to cause global warming effects. The efficiency of the refrigeration system with this technology is 15% better than the system using HFC refrigerants.

Utilization of solar radiation for cooling can also be used as an alternative sustainable technology to reduce the use of energy from fossil materials in the food chain. The application of solar energy (renewable energy technology) in cold storage which is utilized for the thermal system of absorption refrigeration and for producing electricity has been reported by Basu and Ganguly [10]. Wang and Dennis [11] investigated the energy performance of solar refrigeration systems using both batteries and PCM. It was reported that systems with PCM performed better and could provide significant energy savings than systems without PCM. But solar refrigeration systems with batteries provide higher energy savings than systems with PCM.

The proposed technology combines the advantages of energy efficient refrigeration technology and sustainable energy technology using Bio-PCM. The refrigeration system of the ice machine is integrated with Bio-PCM as a thermal energy store. The refrigerant used for the refrigeration system is a hydrocarbon refrigerant (R-290). The system was also tested with R-404A as a comparison. The refrigeration system cools the raw ice in the molds directly and simultaneously cools the Bio-PCM. Cooling is done from one direction to ensure it can produce crystal clear ice blocks. Such a system can take advantage of the advantages of energy-efficient refrigeration systems using hydrocarbon refrigerants [12].

2 Materials and Method

The type of ice machine performance to be analyzed using Bio-PCM which the author describes in this final project is a study of the application of Bio-PCM which can later be on an ice machine. The analysis carried out included testing the ice machine with Bio-PCM, the purpose of the ice machine printing results is because it is expected that the machine can produce crystal clear ice. Data analysis generated on the machine and data processing obtained from the analysis that has been carried out.

Through a vapor compression refrigeration cycle scheme, the cold released by the evaporator is used to cool frozen media and also Bio-PCM media. The function of the Bio-PCM will later become cold storage so that the cooling space is maintained and the machine does not work continuously and at least the ice machine can have a pause for a few moments so that the temperature is maintained at the freezing point. When the freezing process takes place, it is hoped that the ice machine will produce ice quickly and also crystal clear. The design of the ice machine and also the Bio-PCM pads are described in Fig. 1.

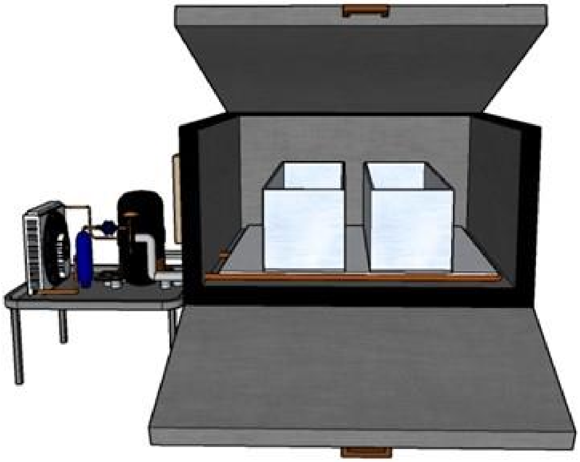

Fig. 1. Design of the crystal ice machine

This research was conducted at the Refrigeration and Air Conditioning Engineering Laboratory, Bali State Polytechnic. Ice mold that has been filled with water and a pump, and the function of the pump is to multiply the water so that the ice results are clear. In the freezing chamber there are 2 ice molds, before being filled with water the ice molds will be covered with tar plastic first, then the mold is attached to a pool pump with a pressure of -+ 1500 L/h. Starting with turning on the cooling machine according to the temperature setting (-15 °C) and ensuring the engine runs normally, namely the refrigeration system according to working pressure and the engine starts. In testing the data is recorded every 1 hour which includes as in the experimental stage above, namely refrigerant and air temperature, air RH, low and high pressure, voltage and current strength, air flow velocity, and changes in material weight.

3 Result and Discussion

The results obtained when testing the crystal block ice machine with Bio-PCM pads obtained data such as refrigeration machine system data, PCM data, ice chamber data, ice block formation growth, and power and energy consumption data. Tests are carried out in real time with time variations every 10 seconds for test parameters recorded with a data logger and every 4 hours for manual recording such as the growth of ice crystal formation in molds. The principle of forming ice crystal blocks besides using the concept of one-way heat transfer, in this case from the bottom up, a device in the form of a water pump is also used to keep the water circulating in the mold. This makes the resulting ice very clear as crystal during the ice freezing process because there is no air or gas trapped in the ice. Based on the design and thermodynamic simulation results using the U-RefS program, the production capacity of crystal ice blocks that can be produced using a 2.05 kW (2.75 Pk) refrigeration machine with refrigerant R-404A is 215.02 kg with a production time of 15.6 hours or the equivalent of 0.331 tons of ice per day. This result is obtained with the assumption that all cooling capacity can be transferred properly into the ice tray. This design does not take into account the direction of heat transfer only from one side of the heat transfer field, considering the difficulty and complexity of simulating heat transfer with one direction. From the data of this test, an analysis of temperature and energy performance was carried out as well as an analysis of the production capacity of the crystal block ice machine with double molds that have been made in the Refrigeration Lab, Department of Mechanical Engineering, Bali State Polytechnic. Analysis of the effect of using PCM pads was also carried out.

3.1 Temperature performance of crystal block ice machine refrigeration system

In Fig. 2 to Fig. 3, variations in the temperature of the refrigeration system are presented during the production process of ice crystal blocks. Where T1 is the temperature of the refrigerant leaving the evaporator (Fig. 2).

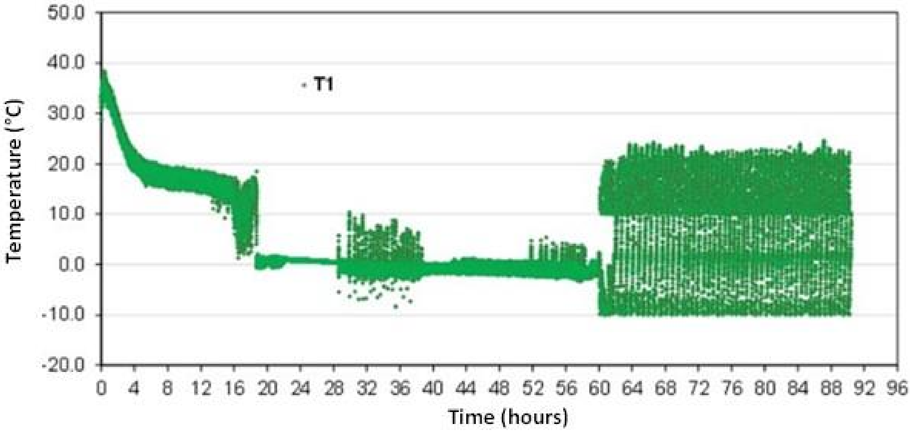

Fig. 2. Refrigerant temperature leaving the evaporator (T1) during the crystal block ice production process

Whereas in Fig. 3 the temperature variation of the refrigerant entering the evaporator is shown. From the two figures, it is obtained that the temperature decreased quite drastically during the pulling down stage from the start of operation to 16 hours. After that, it was relatively stable with a temperature difference or degree of superheat in the range of 12 °C. The two temperatures fluctuated greatly when the refrigeration system underwent an On-Off cycle, especially on the fourth day where the influence of PCM was very visible.

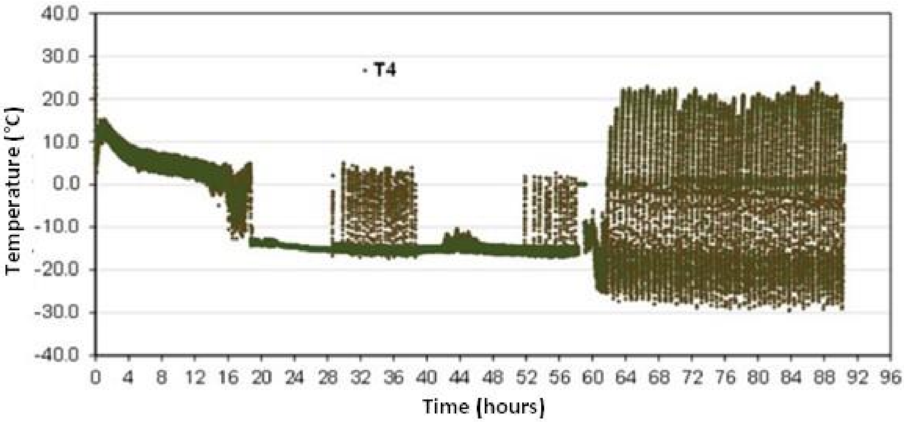

Fig. 3. The temperature of the refrigerant entering the evaporator (T4) during the crystal block ice production process

3.2 PCM temperature performance

To be able to find out that the PCM pads can function properly, temperature measurements are carried out at several positions in the PCM pads. Measurements are installed spread over the entire PCM pad including the inlet side of the evaporator (T_PCM2) and also the exit side (T_PCM4). The results of the test are presented in Fig. 4. It can be seen from the graph that the PCM around the inlet of the evaporator can reach the lowest temperature beyond the freezing point of the PCM. While on the evaporator exit side, the highest PCM temperature is still above 0 °C during the production process. It is also clear that there is an increase in PCM temperature from 17 to 60 hours which indicates a decrease in the performance of the refrigeration system. And the refrigerant deficiency system has been identified (there is a leak). Then the leak is repaired and then the refrigeration system can operate normally again.

3.3 Energy performance of crystal block ice machine

In this study, the energy performance of crystal block ice machines was measured using a power analyzer. The results of measuring power consumption during the production process are presented in Fig. 5. In the first hour of operation, there is an increase in power consumption up to 2.3 kW. After that it gradually went down and in the end it was relatively stable after operating for about half a day. In this test, the On-Off cycle had started to occur at 28-29 hours, but the cycle then stopped at 39 hours. This indicates a symptom of the cooling capacity of the refrigeration system of the crystal block ice machine. decrease. This can also be observed from the refrigeration system temperature data and PCM temperature data

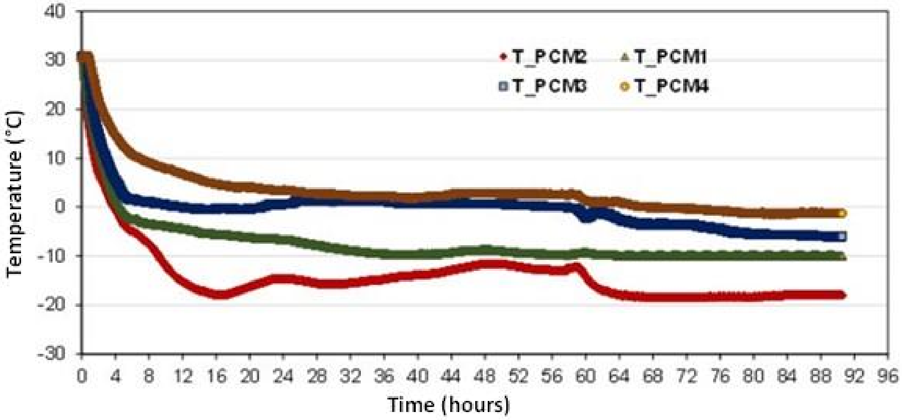

Fig. 4. Bio-PCM temperature at various positions around the evaporator PCM

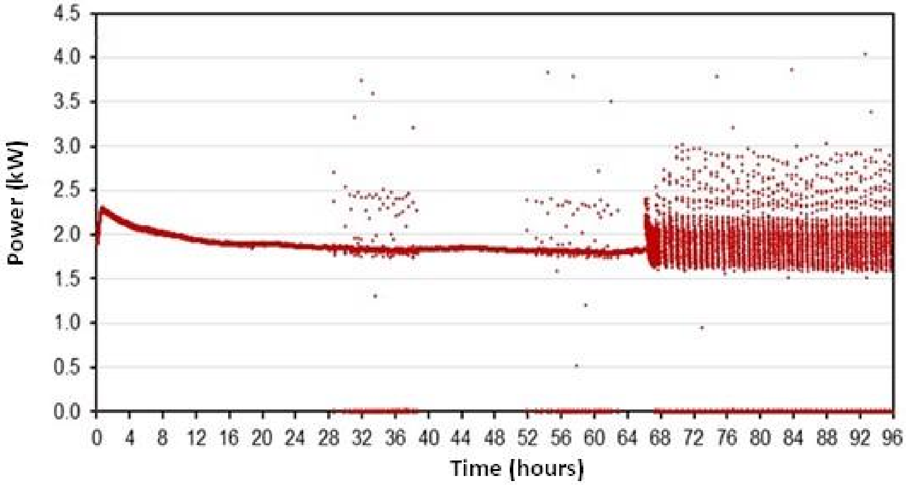

Fig. 5. Variation of crystal block ice machine power during the production process

In order to evaluate the power variations in the production process in more detail, the variations in the power of the crystal block ice machine successively for the 1st to the 4th day. On day 1 of the crystal block ice machine operation, there were no significant fluctuations. Starting from the second day, an On-Off cycle was seen, which was more intensive on day 4 after the leak was repaired in the refrigeration system and filled with refrigerant with the optimal amount of filling. The On and Off cycles in the refrigeration system of the crystal block ice machine which can be identified from the power graph in Fig. 6, are the real influence of the Bio-PCM pads on the evaporator. The refrigeration system operates shorter than the downtime. Even though the refrigeration system is not operating, the process of cooling and forming ice still occurs. This is due to the cooling ability of the Bio-PCM after successfully storing cold energy when the refrigeration system is on. Cold energy is released into ice production without a significant decrease in temperature.

A more detailed comparison of the On-Off cycle on crystal block ice machines without and with Bio-PCM can be seen in Fig. 6 and Fig. 7. In Fig. 6 the on-off cycle is not affected by the PCM, because the PCM has not frozen as a result of a refrigeration system that lacks refrigerant. It is clear that the life time (On) is much longer than when the engine is off (off). On the other hand, Fig. 7 shows the effect of the bio-PCM pad, although it is not optimal, it already appears that the On time is shorter than the Off time.

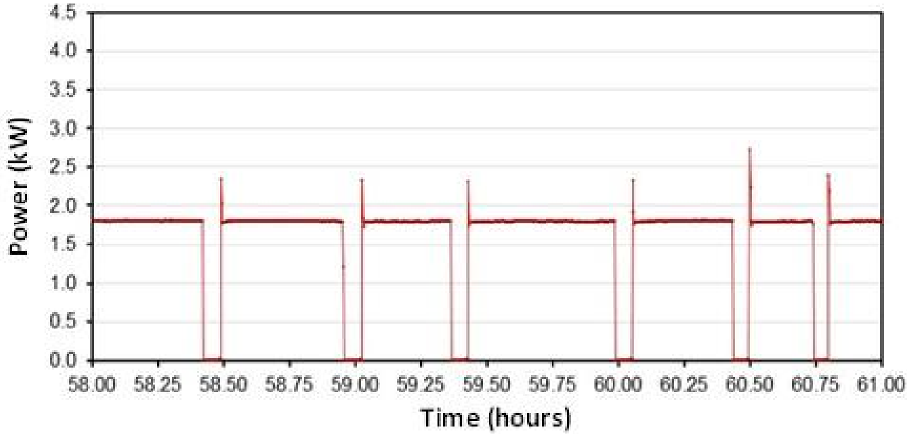

Fig. 6. Power variation of crystal block ice machine with On-Off cycle without Bio-PCM effect

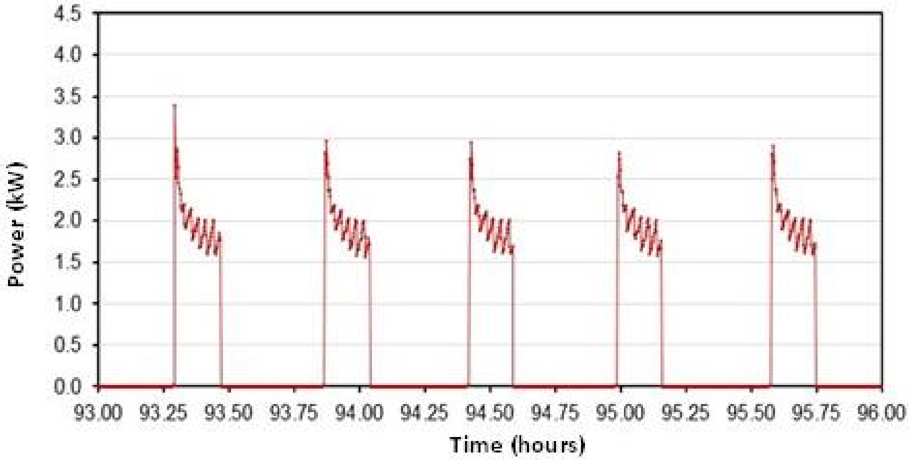

Fig. 7. Power variation of crystal block ice machine with On-Off cycle and bio-PCM effect

This can provide an advantage in reducing energy consumption as a result of the Bio-PCM pad. The reduced energy consumption is due to the significantly shorter operating time compared to that without the influence of the bio-PCM pads. This is discussed in more detail in Fig. 8.

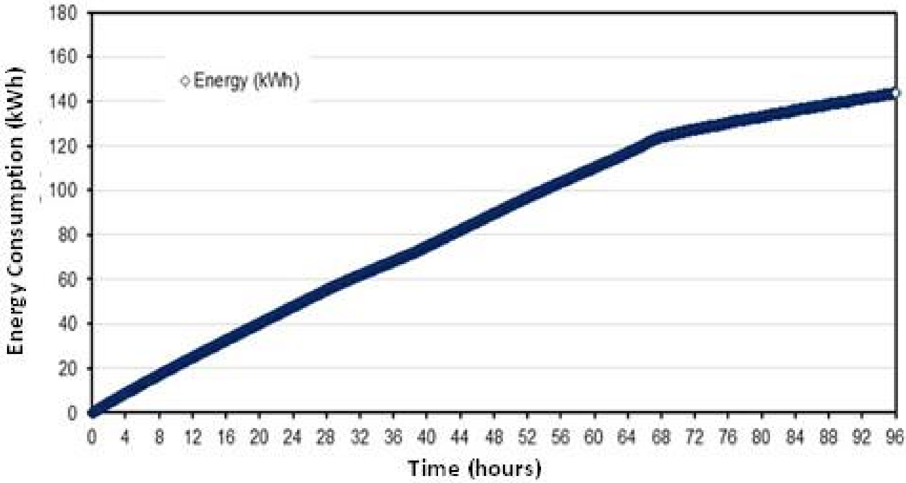

Fig. 8. Energy consumption of block ice machines during the production process with the Bio-PCM effect

Fig. 8 illustrates the increase in energy consumption over time in the production process. The increase in energy consumption from the start of operation to 68 hours on the third day was relatively sharp. It has been explained previously that during this operating period the effect of Bio-PCM did not exist as a result of the cooling capacity of the refrigeration system which decreased because the refrigerant leaked. Starting from the 68th hour, after the refrigeration system was repaired, the effect and function of the Bio-PCM pads appeared. In the aspect of energy consumption, there is a decrease in the rate of energy consumption which is indicated by a sloping energy graph. The total energy consumption during the crystal block ice production process is 143.6 kWh.

3.4 Production capacity of crystal block ice machine with Bio-PCM

In terms of production capacity, crystal block ice machine is relatively stable compared to temperature and energy performance. Likewise, the system with or without the Bio-PCM effect is also relatively the same. The thickness growth of ice crystals in molds is presented in Fig. 9. From the R-404A Ph diagram by entering the temperature (T) in °C and pressure (P), the enthalpy for each point is obtained as follows:

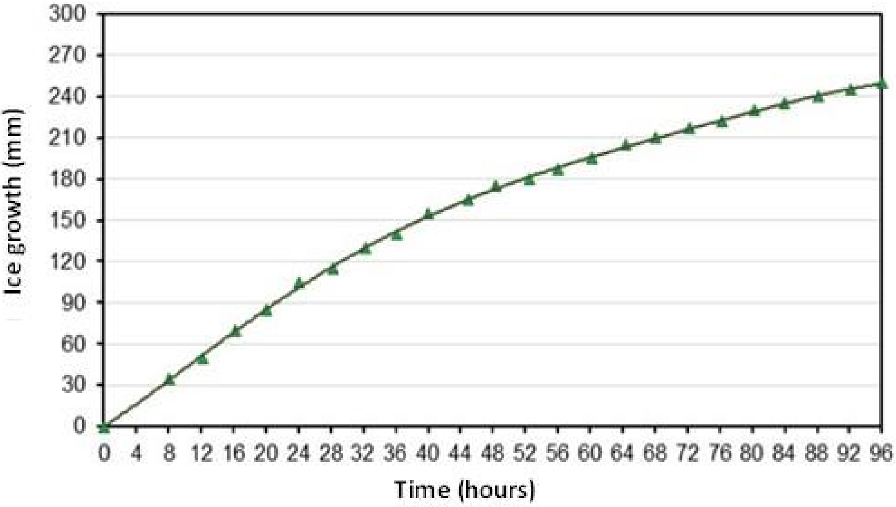

Fig. 9. Growth rate of ice crystals in a horizontal block-shaped mold

The thickness of the crystal ice that is the production target is 250 mm according to the needs of the international market. This thickness can be achieved with an operating time of about 4 days or 96 hours. The production of crystal block ice is relatively slow compared to other ice products. This is caused by the cooling process that only comes from one direction. In this test, the production of crystal block ice weighing 215 kg in 4 days or around 54 kg per day was obtained.

4 Conclusion

The temperature performance of the crystal block ice machine with Bio-PCM pads has been determined. The refrigeration system obtained from a crystal block ice machine operates at temperatures of refrigerant leaving the compressor and leaving the condenser in the range of 70-88 °C and 28-34 °C respectively; the evaporating temperature is -18 °C in operation without the effect of bio-PCM and around -25 °C to -28 °C with the effect of Bio-PCM and the system manages to maintain the superheat temperature of the refrigerant entering the compressor at around 12 °C. The temperature of the Bio-PCM in this test has not all reached the freezing point, so the function of the Bio-PCM in this test is not optimal. Energy performance of crystal block ice machine with bio-PCM pad effect is relatively lower compared to without Bio-PCM effect. In this study, the average power consumption of the crystal block ice machine is 1.90 kW with an operating time of 96 hours and the energy consumption obtained in one production run is 143.6 kWh. The production capacity of crystal ice blocks weighing 215 kg in 4 days or about 54 kg per day. This production capacity when compared with the results of design and thermodynamic simulations is much lower. Based on the results of the design and thermodynamic simulation, the production capacity of crystal ice cubes that can be produced is 215.02 kg with a production time of 15.6 hours or the equivalent of

0.331 tons of ice per day. This difference is due to the fact that the design has not taken into account the direction of heat transfer from only one side of the heat transfer field.

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