Corn oil phase change material (PCM) in frozen food cooling machine to improve energy efficiency

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Abstract. Freezer cooler (CF) is one of the cooling equipment for the storage needs of frozen food at low temperatures. CF is an indispensable tool for storing food and drinks to be durable. So, it is safe for consumption. Ice cream products, for example, are susceptible to temperature variations and are easily damaged during storage. Temperature fluctuations can cause dramatic adverse effects on the quality of frozen food, ice re-crystallization temperature in ice cream, and this can create substantial economic losses, and degrade the quality of frozen food. Maintaining a stable temperature in frozen food storage is very important. Current CF cooling technology consumes large amounts of electricity. It is essential to develop research on CF cooling engines that are energy efficient and environmentally friendly. Current technology makes it possible to add PCM to the walls of the cooling machine. During the phase change process, the temperature remains constant, and a large amount of energy can be stored or released. Refrigeration technology testing with PCM integrated on the evaporator has been carried out in this study and can reduce energy consumption by 4 percentage, increase COP by 6 percentage.

1. Introduction

The main issue that arises in the world today is related to energy issues. The Government, through Law No. 30/2007 on energy, mandates the Blueprint for National Energy Management (BP-PEN 2005 - 2025) and supports the implementation of the 2015-2019 RPJMN terms and the National Research Agenda (ARN) [1], so that energy insertion equipment in industries needs improved efficiency, including the food industry. Refrigeration systems are essential in the food chain, both maintaining safety and quality of food and allowing food supplied from producers to consumers. Refrigeration also has a vital role in reducing post-harvest losses. For the problem of handling perishable food products, freezing technology using a chest freezer (CF) will be very helpful.

CF machines are cooling machines whose freezing temperatures range from -15 ºC to -20 ºC. The cold temperature in the CF is constant and slow so that the food that frozen in the CF is not easy to melt. This is important in storing food. Storing frozen food products will inhibit and stop the growth of bacteria and can kill some types of harmful bacteria up to more than 90% so that the food is not damaged or remains durable. The efficiency of CF machines in the market today can still be improved to reduce energy consumption and environmental impact. The energy-efficient refrigeration technology is accordance with 2016-2019 PNB Strategic Plan of sustainable technology with new and renewable energy concept of thinking; efficient and environmentally friendly application of technology; and the development of new and renewable energy sources. The latest method that can be applied to improve energy efficiency and energy saving is to utilize energy storage technology using thermo chemical storage, which can now use. The energy storage technology classified were as sensible heat storage and latent heat storage [1, 2].

The most attractive storage technology with LHS because of the ability to store and release heat with a large quantity of energy per unit weight of PCM at almost constant temperatures. It can compensate for the imbalance between heat generations and heat consumed [3]. Thus, PCM is an ideal product for thermal management solutions because it can store and release heat energy during the thawing and freezing processes (change from one phase to another). This latent heat storage method has become an exciting topic for a large number of use applications. Latent heat energy storage methods can provide much higher energy with negligible temperature changes compared to sensible heat storage [4]. However, practical difficulties usually arise in applying the latent heat method due to low thermal conductivity, changes in density, and are less stable. PCM research on CF cooling machines where the use of PCM panels (pouches) placed on the freezer wall can maintain a relatively more stable product temperature compared to conventional methods where temperature fluctuations can be ± 1-5^{0}C [5]. In this study, better product storage obtained with a more stable temperature. The above research uses salt based PCM. This type of PCM is very corrosive to materials commonly used for cooling systems [6].

Research on the uses of water based organic PCM using corn oil esters, which is the result of corn oil esterification [7, 8]. Corn oil esters can dissolve very well in water. The real advantage of using organic material compared to salt based PCM is that non-corrosive, has the functional thermal capacity, chemically stable, can be obtained easily on the market and more easily integrated into the cooling machine. Therefore, a study of the application of water based PCM with a mixture of organic materials and their effects on energy performance and temperature of the CF type cooling engine needs to do. The study of the composition of a mixture of corn oil and water esters and testing their characteristics to be applied on CF machines with temperatures lower than -15 ^{0}C is very necessary [9]. Utilizing the PCM will be both bag type (pouch) and PCM integrated with the evaporator and modifications that need to made to the CF type cooling system, so that the Coefficient of Performance (COP) increases and the temperature performance of the CF type cooling machine also increases so that its influence on consumption the energy can be determined [10]. The COP and energy performance, the superiority of chest freezer refrigeration technology that utilizes the integrated PCM technology in its evaporator compared to conventional chest freezer cooling machines are discussed in this paper.

2. Methodology

2.1. Research types and designs

To obtain comprehensive achievements and outputs preliminary observations and literature studies have preceded this research, an experimental study carried out from a concept of using an integrated Bio-Based PCM on its evaporator in a chest freezer (CF). CF engine cooling capacity explicitly made for research purposes, then modified which includes installing a PCM with a thickness corresponding to the outer diameter of the evaporator pipe which is 8 mm so that it fills the gap between the evaporator pipe with the position behind the evaporator. This design change will reduce the mass use of PCM.

The use of corn oil esters will undoubtedly reduce the purchase cost for the PCM because it is a natural ingredient that quickly founded in Indonesia. Isolation between the pipe and the wall removed, while to increase heat transfer, an aluminium plate that is tightly attached to the evaporator pipe is added. Then fill in the product in the form of a plastic box and filled with water as a substitute for the product (ice cream). Products arranged in CF and a specific position mounted thermocouple to measure their temperature during the test. Measurement method and measuring instrument were placement according to ISO23953-1 Standard 2012. The position of product placement and measurement can see in Figure 3 Product temperature measurements at various areas aim to obtain temperature performance from the CF system.

Instrumentation also includes the installation of temperature measuring instruments and power meter in the refrigeration system of the CF system to obtain energy performance data. In the evaporator section, it integrated with PCM by embedding the PCM between the evaporator pipes which previously had to open the inner plate of the freezer and finish installing the PCM again. The chest freezer also equipped with a thermostat that functions to control the operation of CF Figure 3.1. The sensor of the thermostat is placed on the inner wall of the freezer, as can be seen in Figure 3.2. Parameters that are independent variables including product temperature, PCM temperature, the temperature of each state of the refrigeration system, and power consumption. Whereas the dependent variable parameter consists of energy consumption, COP system, and cooling rate.

Research instruments and equipment needed and used for experiments include tools, temperature sensors, data logging systems, power meter and one computer unit, CF Coolant Prototype. Figure 3 Measurement instruments and prototype CF machines made for testing. The data scan 7320 acquisition data instrument kit, completed with K type thermocouple sensor for temperature measurement and PC data acquisition: Data scan 7320 (Measurement System Limited), this device consists of 16 digital channels that can be used to record temperature, pressure and flow rate data as needed when testing the thermal cycle of PCM materials and testing the energy and temperature performance of the cooling machine CF. Power Analyzer TES 3600 device is used to measure and record electrical power. For analysing data, the 2015 PNB license EES (Engineering Equation Solver) software program to be used. Collection and Analysis; Secondary data obtained from the results of literature studies; primary data obtained through direct measurements recorded from the data logger. Calibrate all sensors and transducers to reduce uncertainty from measurement results.

Experimental data processing uses the EES program for its energy performance (COP and EER), to display graphs of product distribution and temperature fluctuations before and after the freezer is equipped with an ejector and integrated with PCM with the MS-Excel program

Data Analysis Techniques; this research is an experiment using a CF engine explicitly made for this. The main parameters temperature and pressure in the system are used to verify and calculate performance with the help of the ESS program to compare between the second is with PCM and not with PCM. The PCM used was corn oil esters with a composition of 0.25% in pure water solution to obtain a working temperature of PCM -15ºC to -20°C [9].

Data of pressure (P, Psig), temperature (T, ^{0}C), voltage (V, volt), Current (I, Ampere), obtained by direct measurement on each type of test with the help of measuring instruments and data acquisition that is testing at a 5 kg water load. Digital thermostats are installed in the cabin to measure cabin temperature range -15°÷-5º C. Measurement of temperature and energy performance parameters is carried out simultaneously and based on real-time. Data collection system used a data logging system and has sufficient logging capacity for all parameters observed and measured and synchronized with the power analyser for the same measurement time. The results of the calculation of the equations above were plotted on the graph.

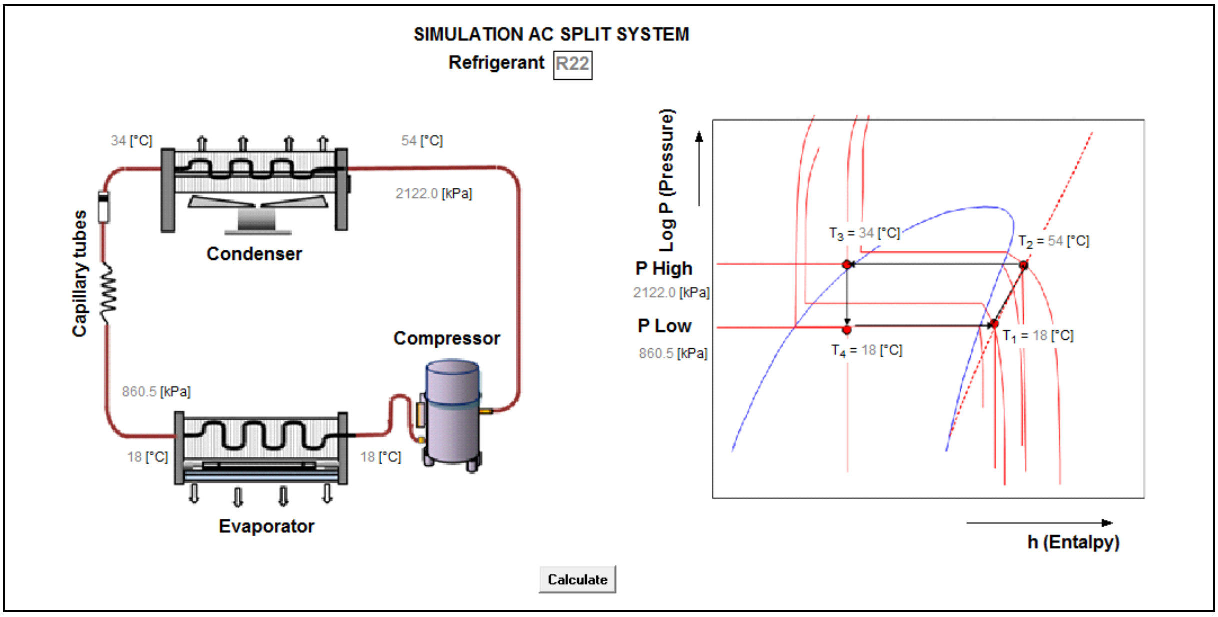

Figure 1. The Simulation AC split type diagram.

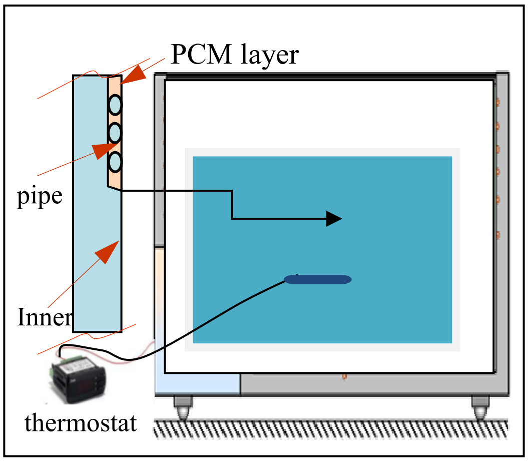

Figure 2. The integration PCM on evaporator (vapor compression cycle) and thermostat sensor.

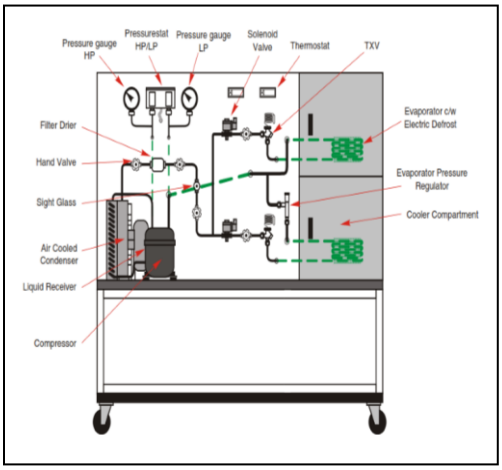

Figure 3. The prototipe CF with two different temperatur evaporator.

3. Results and discussion

CF machines with total cooling capacity (total Q) of the system amounted to 5.982 kW; the Evaporator uses copper pipes with a size of 3/8 inches internal diameter of 8 mm and an outer diameter of 9.5 mm with a total length of 12.6 meters. The condenser uses a copper pipe of 3/8 inch in diameter of 8 mm and an outer diameter of 9.5 mm and has a capacity of 1/2 HP. The expansion device installed is a TXV valve. Hermetic compressors are used for this machine, with a capacity of 1/2 HP. It has been completed and a temperature of -20°C can be reached within 5 hours. The COP value and the MS-excel program is used to display the graph. Temperature testing showed that the performance of the coolant chamber temperature of -15 ° C has achieved.

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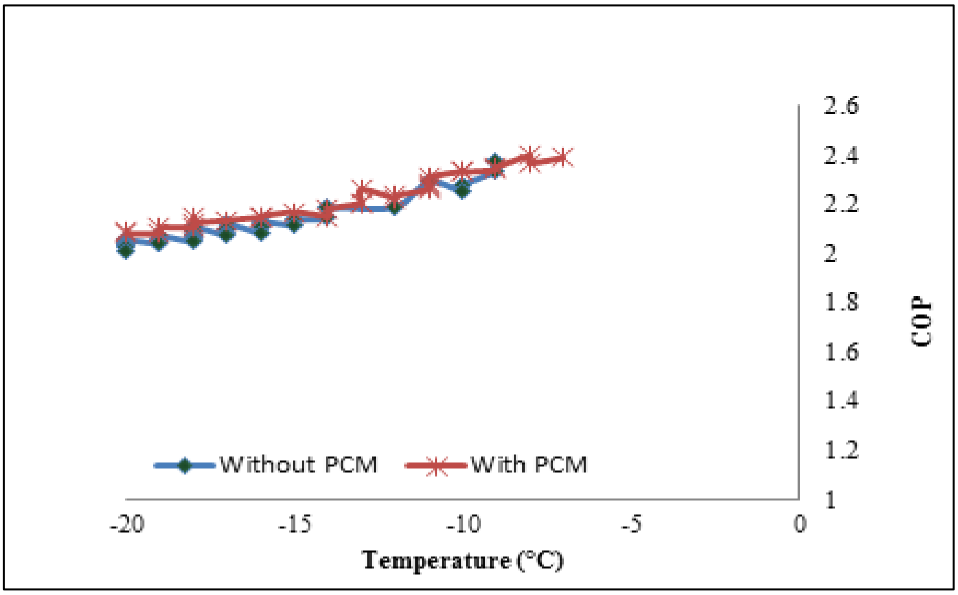

Figure 4. The performance of COP versus (T1) temperature in of the compressor.

Figure 4 shows the performance of COP versus (T1) temperature of the compressor in the compressor. COP value tends to decrease if the temperature (T1) of refrigerant entering the compressor decreases. COP CF with PCM integrated red line and without PCM blue line: based on testing it founded that the average COP for CF machines with PCM is higher at 2.25 while the value obtained without PCM 2.1 so that a COP increase of 6% obtained with the use of an integrated PCM in the evaporator. These results are consistent with the results shown by [11] which states an increase of 6-8% COP with the use of PCM heat exchangers in refrigeration systems.

Figure 5 shows that there is a significant temperature fluctuation in the cooling load in the cabin on CF machines without PCM (blue line) whereas with the use of PCM integrated with the evaporator into the evaporator temperature, the temperature of the water (cooling load) is very stable with temperatures of -2 ºC. Shows that the use of PCM is very well applied for CF to maintain a constant temperature in order to maintain the quality of stored products.

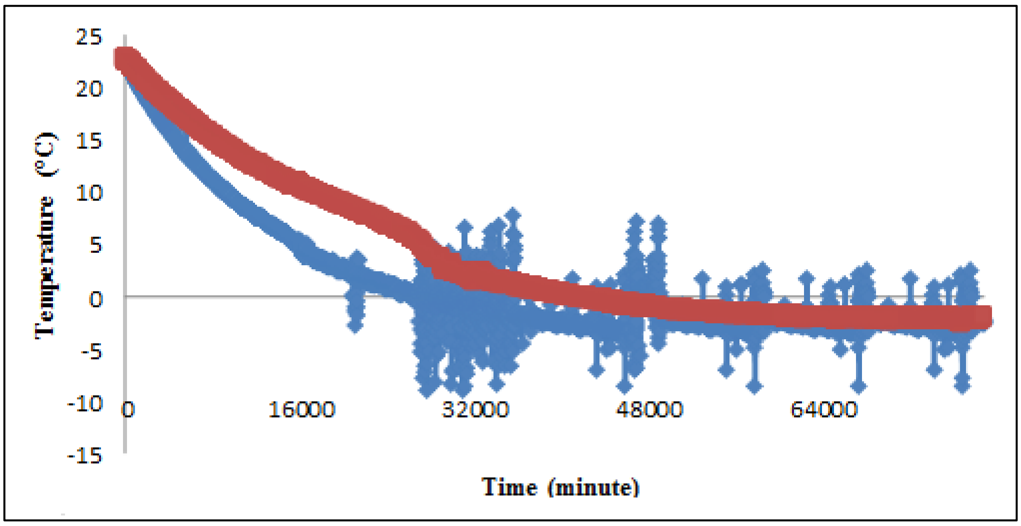

Figure 5. The fluctuation in the cooling load in the cabin on CF machines.

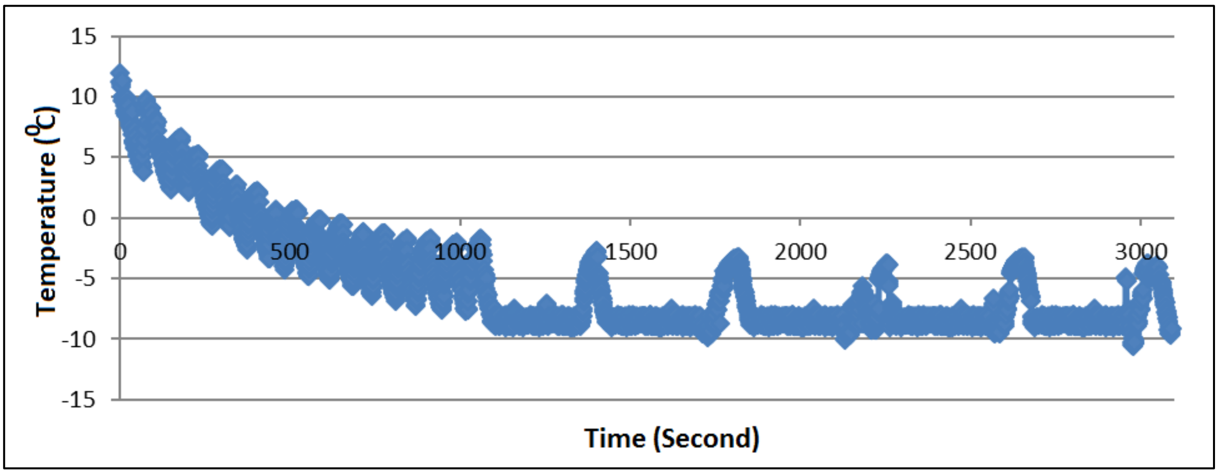

Figure 6. The temperatur freezing of PCM integrated the evaporator.

Figure 6 shows the temperature of the PCM integrated the evaporator freezing at -10°C and the compressor off at -15°C temperature sett. The LHS from PCM used for maintaining the room temperature for longer until there is an increase in temperature to -3 to then the compressor is back on.

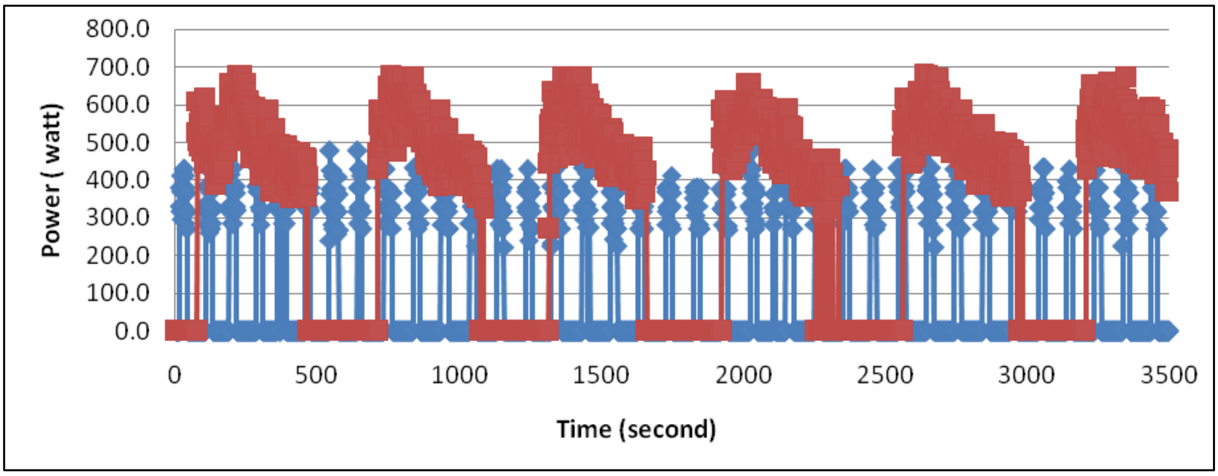

Figure 7. The compressor power usage between the evaporator without and with PCM.

Figure 7 shows the comparison of compressor power usage between the evaporator without PCM, the blue line on the graph with those using integrated PCM see the red line. It is known for testing for 12 hours of total input power usage on compressors with an integrated PCM of 906.50 kW and without PCM of 1770.0 kW so that the reduction in power usage is 71.96 kWh or 4% per hour. from the on-off cycle can be seen by the use of an integrated PCM in the evaporator the period off the compressor on average is more extended than without PCM for a stable cabin temperature at -10 ° C. This causes the average power consumption of 4% lower using PCM compared to with those not using PCM. The latent heat of the PCM can be useful for work that can withstand the temperature of -10° C.

4. Conclusions

We have drawn the following concluding remarks from the results of the present study. The system amounted to 59.82 kW, and Temperature -20 C can achieve within 5 hours, the COP for CF machines with PCM was higher at 2.25 while the value obtained without PCM 2.1 so that a COP increase of 6% obtained by using an integrated PCM in the evaporator. Due to the use of an integrated PCM in its evaporator, it affects the compressor's On-OFF cycle. The compressor off cycle becomes longer than without PCM because the cabin temperature is stable at -10 C for a more extended period. The latent heat from PCM can be useful for jobs that can withstand temperatures of -10 C, and there is a reduced in the power of 71.96 kWh or 4%.

5. References

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