Enhancement of cooling system performance of cold storage by using Salt, Glycol, and Methanol based Phase Changing Materials

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Abstract

One of the efforts to increase the efficiency of energy use, especially in cold storage applications, is by utilizing Phase Changing Material (PCM) in the cooling system. The application of PCM for efficiency energy is by utilizing its latent heat so that food products will remain cold at low temperatures as long as possible. In this study, a combination of conventional cooling systems was carried out using an insulate box in which PCM was added. The type of PCM used is a combination of 70% water added with salt, glycol, and methanol with variations for each sample, namely A1 (12% salt and 18% glycol), A2 (10% salt and 20% glycol), and A3 (8% salt and 20% glycol) as well as for samples B1 (12% salt and 18% methanol), B2 (10% salt and 20% methanol), and B3 (8% salt and 22% methanol). The simulation process is carried out by determining the operational temperature of the cooling system between -2 - 8 ^{o}C. Temperature measurement is carried out inside the coolbox using a type K thermocouple. The measurement process starts when the compressor starts (on mode) from room temperature until it reaches -2 oC and then stops (off mode) until the temperature reaches 8 ^{o}C. The temperature data was collected during 90 minutes of cooling system operation. From the analysis of the performance time of the cooling process and the total operating costs, optimal results were obtained for material A2 (glycol mixtures) and material B1 (methanol mixtures).

Keywords: cooling system performance, cold storage, glycol methanol, and PCM

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1. Introduction

The community's increasing needs regarding daily food needs like vegetables, tubers, seafood, and others. There is an increasing market need; on a large scale, these crops require special handling, so that food products arrive at the market—the hands of consumers—in a form that is still fresh or fit for consumption. Portable refrigerators are indispensable in maintaining food quality, for urgent needs, especially in places far from home, or for transportation of goods, food, blood, and vaccines. Equipment used to maintain product quality at a specific temperature is usually cold storage, which involves low temperatures in maintaining the product. This equipment is vital in the food, beverage, and drug industries. Cold storage was usually used to sell processed food or other products to keep the products sold fresh for a long time [1].

One of the advanced technologies that can overcome these problems is using Phase Change Material (PCM) as a substitute for conventional refrigerants. Refrigerant does not need to work in a continuous state because this material can store heat energy or release it [2]. PCM is divided into three groups, namely organic, inorganic and eutectic. Organic is raw PCM, inorganic is non-natural PCM, and eutectic is a mixture of organic-organic, organic-inorganic, and inorganic-inorganic PCM. Many industries use PCM, whose name is commercial PCM. Each PCM has its advantages and disadvantages. Organic PCM is usually the most widely used [3].

PCM used in refrigeration systems is an application of the principle of latent heat storage. This form of energy storage is based on the enthalpy phase change of the material without a temperature change. PCM can undergo solid-liquid, liquid-gas, or solid-gas transitions. Latent heat storage techniques are more attractive than sensible heat storage methods because of their higher energy storage capacity per unit volume and almost constant temperature during heat storage [4].

In this refrigerator system, two losses were experienced by the compressor as a result of the on/off cycle. First, during the active process, the thermal load of the heat exchanger is relatively higher than that the system controls constantly. Due to the increase in temperature rise, this effect reduces the thermal efficiency. Second, the refrigerant transfer follows the compressor on/off process, resulting in energy losses [5]. PCM applied to the cooling system is placed in the condenser section as a heat storage/evaporator or a cold storage compartment to improve cooling performance [6].

Various studies have been carried out regarding the application of PCM in the cooling system to increase the performance coefficient and energy use efficiency. Cheng and Yuan conducted a numerical study on modeling a household refrigerator system with a heat storage condenser using shape-stabilized PCM. There is an increase in COP of about 19% with continuous heat transfer due to the storage of latent heat from the SSPCM [7].

The effect of PCM on the compressor on/off cycle of household refrigerators has been experimentally investigated by Khan and Afroz. The experimental results show that the number of the compressor on/off cycles in the time tested is about 3-5 times lower than the system without PCM. Experimental results with PCM show that the average compressor working time is reduced by about 5-30% compared to without PCM, and there is a reduction in temperature fluctuations [5].

The development of a new cooling system carried out on refrigerated trucks by adding PCM was carried out by Liu et al. Energy consumption is reduced, and the resulting greenhouse gas (GHG) emissions are much lower. This PCM is very good at maintaining the cooling system at a temperature of -18 °C. PCM has a melting temperature of 26.7 °C and latent heat of 154.4 kJ kg-1[8]].

Pavithran made a CFD simulation related to the effect of combining PCM in a refrigerator. The research found that incorporating PCM maintains the refrigerator's temperature. During this period, the compressor is off by absorbing the heat. The heat enters the system and changes its phase from solid to liquid. This procedure increases the duration of compressor downtime, which reduces energy consumption. The combined horizontal and vertical configuration of PCM fusion is the best for stabilizing the temperature in the system [9].

This experiment aims to determine the performance of PCM with excellent box media in storing cold. To save costs in use or operation, determine PCM performance in saving energy while maintaining cold temperatures in the cool box.

2. Research Methode

The composition of PCM is made with a mixture of Salt, propylene glycol and methanol. The mixing process is carried out with a predetermined composition that is shown on table 1.

Table 1. PCM Variation

No	PCM	PCM Concentration			
		Aquades %	Salt %	Glikol %	Metanol %
1	PCM A1	70	12	18	-
2	PCM A2	70	10	20	-
3	PCM A3	70	8	22	-
4	PCM B1	70	12	-	18
5	PCM B2	70	10	-	20
6	PCM B3	70	8	-	22

Table 2. PCM Freezing Point

No	PCM	Freezing Point ^{O}C
1	PCM A1	-17,78
2	PCM A2	-16,26
3	PCM A3	-15,09
4	PCM B1	-24,31
5	PCM B2	-25,98
6	PCM B3	-29,99

Table 2 shows the freezing point calculation results for each variation, PCM with the lowest freezing point was found in PCM A3 at -15.09°, and the PCM mixture with the highest freezing point was found in PCM B3 at - 29.99°.

The properties of PCM materials can not only be determined by the mass of PCM. However, it is necessary to determine the material's freezing point. In this case, the freezing point of Propylene Glycol can be found on the Material Safety Data Sheet (MSDS), which is -59^{o}C, and the freezing point of Sodium Chloride (Salt) is 809^{o}C. (Teknik et al., 2018).

The experimental set-up for measuring the performance improvement of the cold storage system is shown in Figure 1. The research consists of a conventional cooling system device which includes a compressor 1/3 PK, condenser and cool box which is filled with PCM. Type K thermocouples are used for temperature measurements and Adruino uno is used as a data logger in these measurements. The results of temperature readings will be processed and displayed using a personal computer

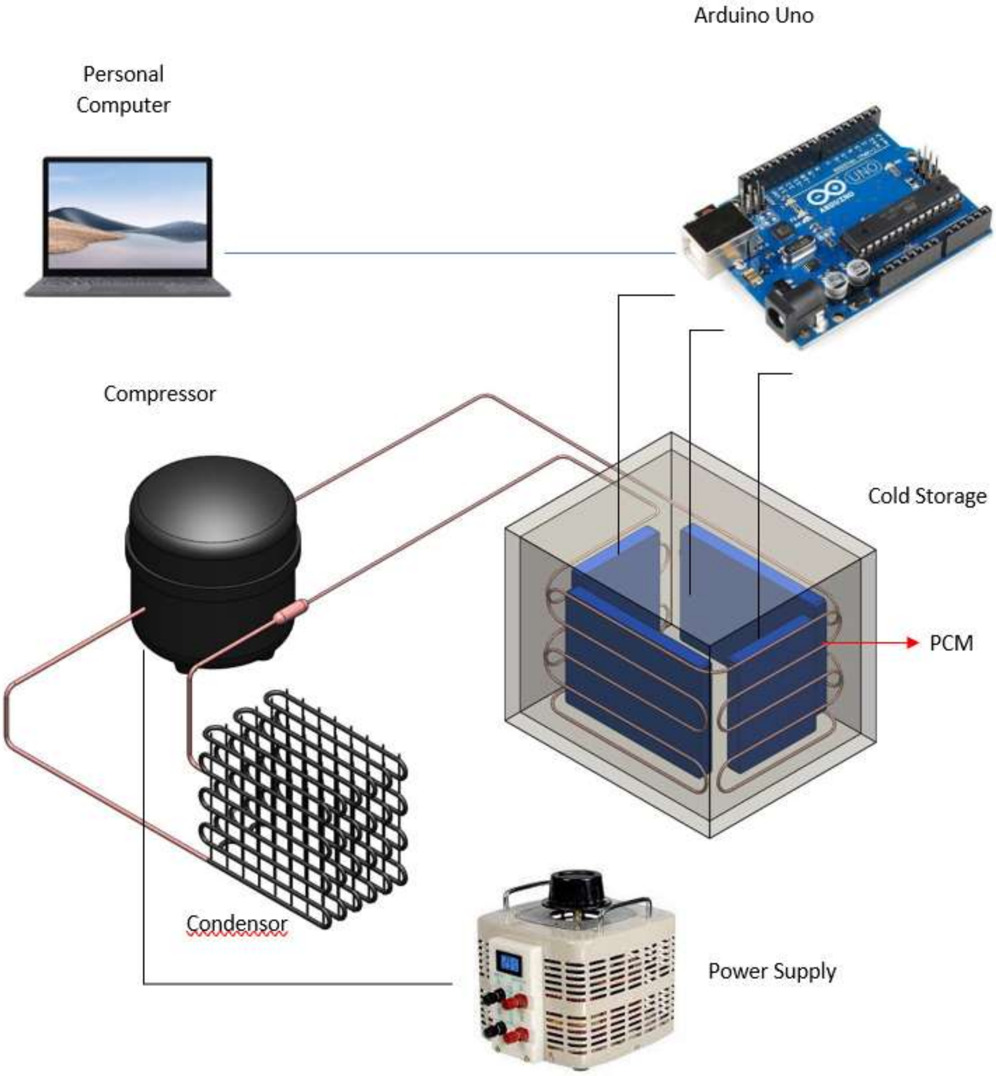

Figure 1. Schema of system

The simulation process is carried out by determining the operational temperature of the cooling system between -2 - 8 oC. Temperature measurement is carried out inside the coolbox using a 3 thermocouple type K. The measurement process starts when the compressor starts (on mode) from room temperature until it reaches -2 oC and then stops (off mode) until the temperature reaches 8 ^{o}C which is 1 operational cycle. The data collection process was carried out in 5 operational cycles.

3. Result and Discussion

A review of cold energy storage via solid-liquid phase shift was conducted, focusing on applications for cooling buildings and PCMs suitable for that temperature range. The primary emphasis of studies based on numerical calculations or experimental work was the change in interior air temperature caused by the installation of PCMs. A great deal of emphasis was also placed on the possibility of decreasing cooling's electricity usage. To determine this potential, it was essential to know the system's charging/discharging rate, PCM mass, air flow rate, inlet/outlet air temperatures, etc.

In most of these experiments, paraffin was utilized as PCMs, but salt hydrates, water, or fatty acids were employed in a few instances. Researchers suggest that PCMs installed in buildings improve structures' thermal and energy performance. If PCMs are incorporated into the building's envelope, thermal comfort rises since internal temperatures do not grow and shift as quickly.

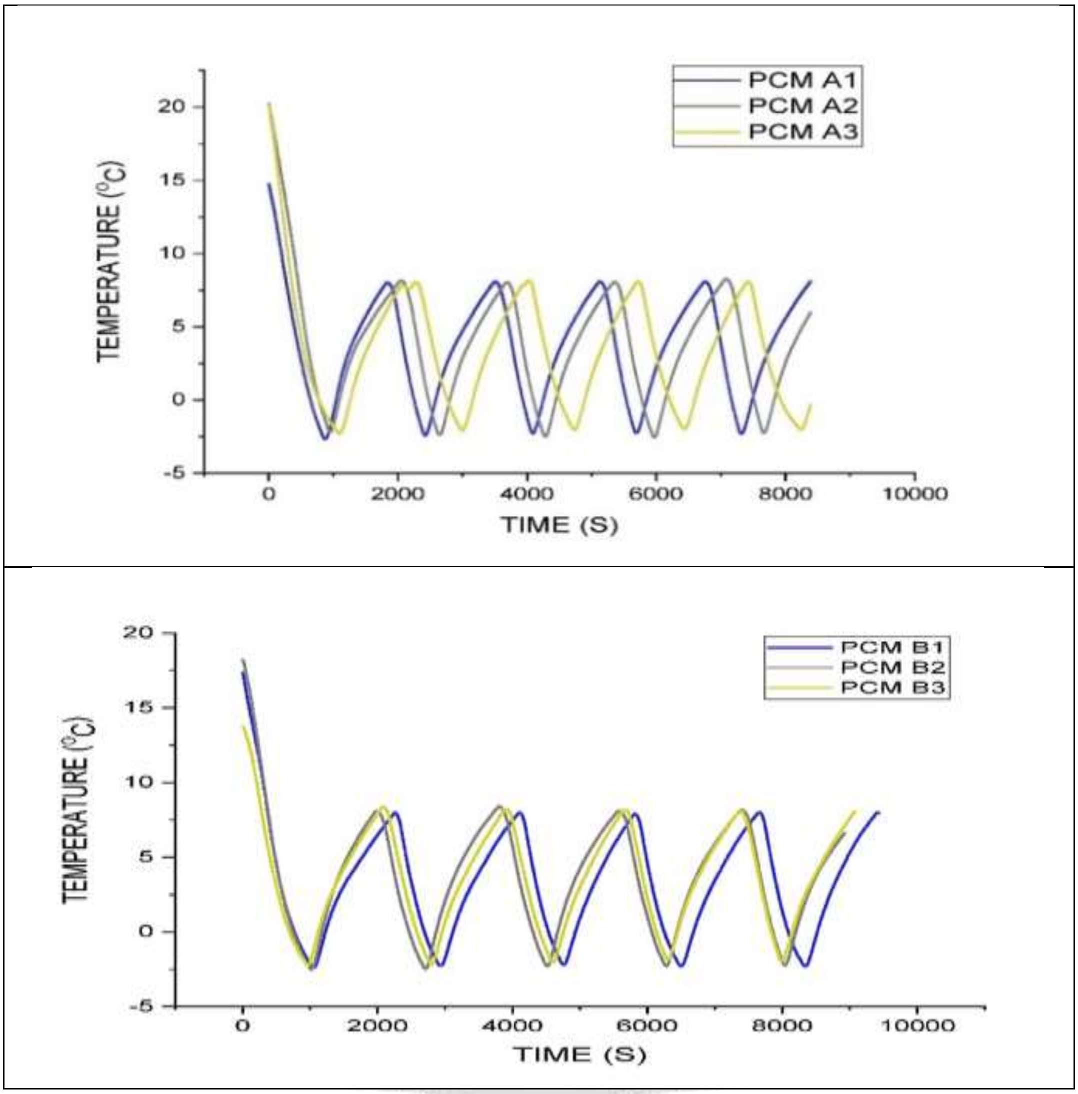

Figure 2. (left) Comparation of temperature PCM A (A1, A2, A3) and PCM B (B1, B2, B3)

In Figure 2, it can be seen that the performance tests of PCM A1, A2 and A3, in this experiment the temperature was reached at -2°C an the highest temperature at 8°C. PCM A1 takes average time of 8.13 minutes in OFF mode and 14.93 minutes ON mode, while PCM A2 takes 8.18 minutes in OFF mode and 15.44 ON mode. PCM A3 takes an average time in ON mode 10.64 minutes and 15.39 minutes in ON mode. From the results it can be seen that PCM A2 with a mixture of 10% NaCI, 20% propylene glycol and 70% Aquades, has better performance compared to PCM A1 and A3.

Meanwhile Figure 3 shows the comparison of PCM with methanol. From the result it can be see that the PCM performance with methanol content (freezing point of -97°) can be stored cold more optimally. From the three mixed variables, namely B1, B2 and B3, the best mixture for cold storage is shown in PCM B1 (8% Salt, 22% Methanol and 70% Aquades)

In addition to analyzing PCM performance, power efficiency calculations are also carried out on the cool box using the power requirement formula in 90 minutes for each PCM variable. From the results shown in

Figure 4, it can be concluded that the PCM compositions that are capable of producing the minimum compressor performance in ON mode are PCM samples A1, A2, and B1.

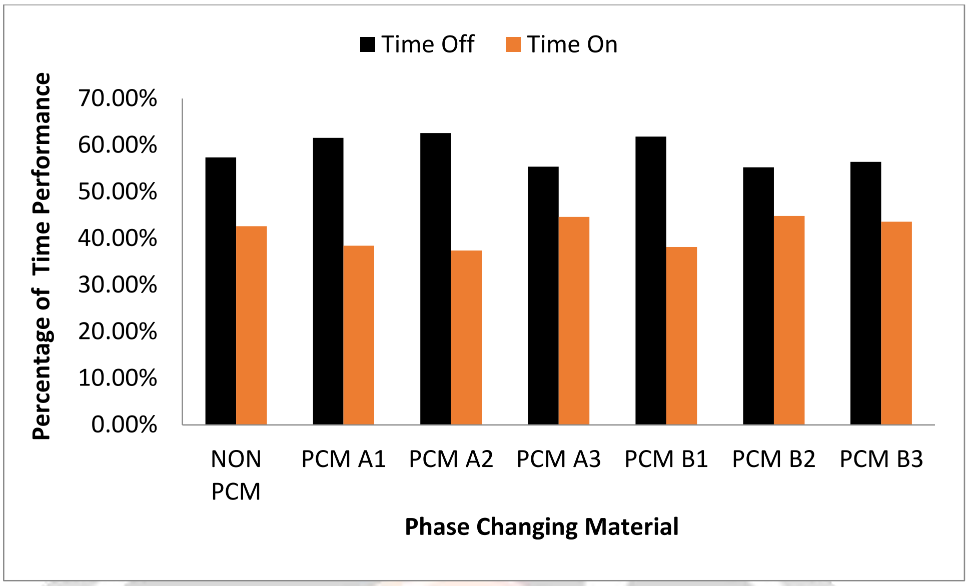

Figure 4. Percentage of time performance in difference PCM composition

In addition, an analysis of the power requirements required by the PCM during 90 minutes of operation is carried out. After getting the power requirements of each PCM, we can then calculate the electricity costs needed by the cool box in 90 minutes of operation, with an estimated price/kWh in the South Tangerang area in September, which is IDR 1,666.66/kWh. From the data shown in Table 3, it can be seen that the PCM with the most efficient power consumption is PCM A2 (with a glycol mixture) at a cost of Rp. 164,201 which is cheaper than without using a PCM of Rp. 184,726. Meanwhile, for the mixture (methanol) the best performance was shown in PCM B1 at a cost of Rp.167,899.

Table 3. Power System Needed

NO	PCM	Power Needed (watt)	Price /kWh (Rp)	TOTAL (Rp)
1	NON PCM	110.88	1.666	184.726
2	PCM A1	101.49	1.666	169.082
3	PCM A2	98.56	1.666	164.201
4	PCM A3	117.77	1.666	196.205
5	PCM B1	100.78	1.666	167.899
6	PCM B2	118.38	1.666	197.221
7	PCM B3	115.016	1.666	191.617

4. Conclusion

In this study a combination of conventional cooling systems has been carried out using an insulate box added with PCM. The application of PCM in this cooling system aims to increase the efficiency of energy use through utilization of its latent heat, so that the cooling temperature of the coolbox will be maintained during the PCM defrosting process even though the compressor is not turned on. Thus the food product will remain cold at low temperatures as long as possible. The type of PCM used is a combination of 70% water plus salt, glycol, and methanol with variations for each sample, namely A1 (12% salt and 18% glycol), A2 (salt 10% and 20% glycol), and A3 (8% salt and 20% glycol) and for samples B1 (12% salt and 18% methanol), B2 (10% salt and 20% methanol), and B3 (8% salt and methanol 22%). The operating temperature of the cooling system is between -2 - 8 oC. The temperature in the coolbox was measured for 90 minutes using a type K thermocouple which started when the compressor was on (on mode) from room temperature until it reached -2 oC then stopped (off mode) when it reached 8 oC. From this research, optimal results were obtained, namely A2 material (glycol mixture) with a percentage of performance time from the compressor (ON mode) of 38.44% and a total operational cost of Rp. 164,201. Meanwhile for the methanol mixture, the best material composition is material

B1 with the percentage of performance time from the compressor (ON mode) which is 38.18% and the total operational cost is Rp.167,899.

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