B-005

ENERGY ANALYSIS OF EUTETIC PHASE CHANGE MATERIAL (PCM) BASED ON DISCHARGING PROCESS

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Abstract

Energy storage materials are now considered as a promising technology to support Indonesia's growing energy needs. One way is to use Phase Change Material (PCM) based thermal energy storage. Phase Change Material is a type of heat energy storage that is able to maintain temperature within a certain time limit. In this study the PCM used was eutetic with a mixture of ingredients, namely water, salt, Acetic Acid and tapioca flour. Where the material was chosen because it is an organic material, easy to obtain, inexpensive and has characteristics that support it for use as a low temperature storage application. The purpose of this study is to determine the energy stored in certain PCM processes. The PCM manufacturing process involves mixing all the ingredients in a magnetic stirrer at 70°C for 5 minutes. then, the PCM application stage is to determine the temperature change during the Charging (Freezing) and Discharging (melting) processes. In this study the heat storage (Q) of PCM 1, PCM 2, and water PCM/ice cubes samples was 494.51 kJ/kg; 489.91 kJ/kg; and 463.13 kJ/kg. So that it can be written that the material composition of PCM 1 has a greater energy storage value compared to conventional PCM/ice cubes.

Keywords: *Charging; Discharging; Encapsulasi; Eutetic; Phase Change Material (PCM)*

INTRODUCTION

Current energy needs are a primary need in supporting all aspects of people's daily lives. Every society, especially in Indonesia, requires an increase in the amount of energy or an evaluation of the increase in energy demand. Therefore, one of the efforts that can be made to increase the efficiency of energy use is by having thermal energy storage. Phase change materials (PCM) are materials that melt and solidify at nearly constant temperatures, and are capable of storing and releasing large amounts of energy when subjected to a phase change (Saputro, 2019). Latent thermal energy storage using a phase change material (PCM) has been suggested to improve performance, due to the large energy storage density and minimal temperature change during phase transitions. Phase change energy storage technology has been a topic of much investigation to date because it has many industrial applications including aerospace, air conditioning and refrigeration, solar heat storage systems, and building heating (Rasta, 2022).

Phase Change Materials or materials that change phase have 2 types of heat energy storage methods, namely latent heat storage and sensible heat storage (Saputro, 2018). Actually, heat energy storage can be stored in the form of latent heat, sensible heat or both. However, using this phase change material as heat storage is a relatively small volume of material that can store heat in a large capacity by absorbing and releasing heat energy that occurs at almost constant temperatures (Haryowadigdo, 2017). This phase change material (PCM) uses the basic principle of latent heat from the solidification and melting processes. The thermal energy when a material is transferred from a solid to a liquid or from a liquid to a solid is called a "phase" change (Mardliah, 2016). The working principle of Phase Change Material (PCM) can be seen from the graph in Figure 1 below:

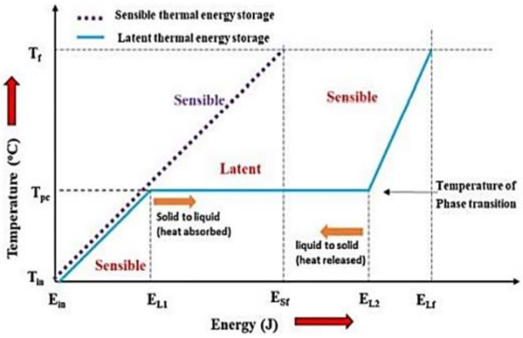

Figure 1. *phase change material (PCM) temperature curve*

The workings of the phase change material itself is by absorbing heat from the room so that the PCM temperature will increase. When the melting point of the PCM has been reached, the phase will turn into liquid (sensible heat), then the process of absorbing heat by the PCM is quite large without any increase. temperature (latent heat). Then the temperature will be constant until the melting process ends. When the ambient temperature decreases, the PCM phase will turn into a solid, in this condition the PCM releases heat. Storage density of PCM is equal to 5 – 14 times storage of sensible density in the same volume (Haryowadigdo, 2017).

PCM is classified into 3 namely organic, inorganic, and eutetic. Organic PCMs can be aliphatic or other organic. In general, organic PCMs have a low temperature range. Organic PCMs are expensive and have a low average latent heat per unit volume and low density. Most organic PCMs are flammable in nature (Pudjiastuti, 2011). The inorganic PCM does not cool too much and the heat of smelting does not decrease during rotation. Inorganic PCM has good thermal conductivity and is non-flammable. The water content in inorganic PCM is high so the price is cheaper than organic PCM (Janarko, 2017). Whereas eutetic PCM is a composition with the lowest melting of two or more components, each of which melts and freezes to form a mixture of crystalline components during the crystallization process (George 1989). PCM has several properties, namely the thermal properties possessed by PCM, namely the melting temperature according to the desired room temperature, high latent heat enthalpy per volume to absorb as much heat as possible, high specific heat capacity to store additional sensible heat (Umar, 2020). The physical properties of PCM include phase balance, high specific gravity, small volume change, and low evaporation pressure. Phase stability during melting and freezing will be advantageous in controlling heat storage temperatures, and high specific gravity will reduce the size of the storage vessel, small volume changes and low evaporation pressure will reduce problems in the storage (Korawan, 2019). kinetic and chemical properties, PCM has no further cooling, PCM has long chemical stability, is suitable for construction materials, is non-toxic and has no fire hazard (Sharma, 2009).

PCM is capable of storing and releasing large amounts of heat. Heat is a form of energy. If a substance receives and releases heat, it is possible that there will be a change in temperature which is known as sensible heat and a change in the phase of the substance known as latent heat (Ermadhani, 2016). Heat is divided into 2 namely sensible heat and latent heat. Sensible heat is the heat required to increase or decrease the temperature of a substance without changing the phase of the substance. The sensible heat equation is as follows:

$$Q = m.C_p.\Delta T \quad (1)$$

Where :

Q = heat energy released/accepted by substance (J)

m = mass of substance (kg)

Cp = specific heat (J/kg.K)

ΔT = temperature change (K)

Latent heat is the heat required to change the state of matter, but the temperature remains constant. The latent heat equation of a substance can be written as follows:

$$Q = m.L \quad (2)$$

Where :

Q = heat energy released/accepted by substance (J)

m= Mass of substance (kg)

L = Latent heat (kJ/kg)

In this research, the PCM used was of the eutectic type with a mixture of water, salt, Acetic Acid and tapioca starch. Where the material was chosen because it is an organic material, easy to obtain, cheap and has characteristics that support it for use as an application for low temperature storage. The purpose of this research was to determine the energy stored in certain PCM compositions and to compare them with conventional PCM/ice cubes.

RESEARCH METHODS

Material

The main ingredient used in this research is water. While the supporting materials are tapioca flour, NaCl, and acetic acid. Tapioca flour, NaCl, and acetic acid with commercial quality materials. Where tapioca flour is obtained in one of the markets in the city of Surabaya. Whereas NaCl and acetic acid are purchased at a chemical store.

Tool

The tools used in this study included 1000 mL beaker glass, magnetic stirrer, 100 mL measuring cup, analytical balance, watch glass, thermometer, thermocouple, spatula, and dropper pipette.

Research procedure

Material Mixing Process

The volume of PCM products made is 1000 ml or 1 liter with the composition of each ingredient according to the following table:

Table 1. Material composition data

Sample	Material Composition			
	Water	NaCl	Tapioca flour	Acetic Acid
PCM 1	80%	5%	10%	5%

PCM 2	79%	4%	15%	2%
PCM Water	100%	-	-	-

The procedure in this study began with weighing solid materials such as salt and tapioca flour according to the sample composition determined using an analytical balance. After that, put all the ingredients and 2-3 drops of food coloring into the beaker glass that has been placed on the magnetic stirrer. Then the ingredients were mixed using a magnetic stirrer with a temperature of 70 °C and a stirring speed of 250 rpm. When the mixture of ingredients has formed a gel dough. Then let it cool down to 30 °C. The gel mixture is then put into HDPE plastic packaging and the PCM product is ready for use. This procedure was carried out for samples 1 and 2, while for PCM water samples, the encapsulation method was only carried out or put in HDPE plastic packaging.

Figure 2. PCM products

Charging* and *Discharging Process

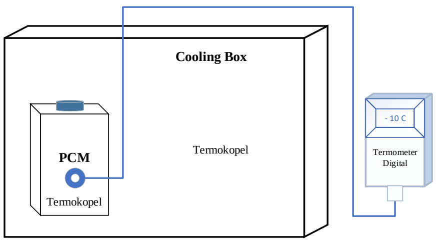

Figure 3. Charging process

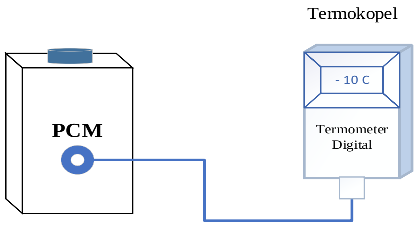

Figure 4. Discharging process

PCM products that are ready, the cooling process (Charging) is carried out in the freezer for 24 hours. During the charging process, the PCM is installed with a thermocouple to determine the temperature profile during the charging process. After obtaining the charging temperature profile data, then the melting process (discharging) is carried out. During the discharging process, an analysis of the temperature profile is carried out until the material reaches room temperature again.

RESULTS AND DISCUSSION

Energy testing on phase change materials (PCM) is carried out by analyzing the temperature profile during charging and discharging.

Testing while Charging

The process of freezing or charging PCM begins by lowering the temperature of the product until it reaches its freezing point. This freezing can occur when the PCM material releases heat energy contained in the system or in the PCM to the environment. So that the PCM material loses energy and begins to squeeze its molecules together to become solid ice or commonly called ice cubes. Charging analysis is carried out starting from putting the PCM product into the freezer until the PCM product freezes completely. The charging process is carried out for 24 hours, every hour the temperature profile that occurs will be recorded. The temperature profile obtained during the PCM charging process is shown in the following graph.

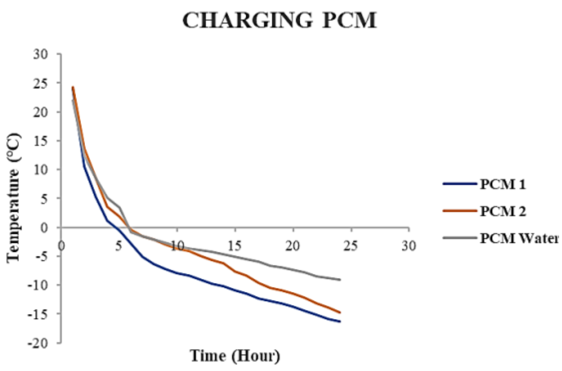

Figure 5. PCM charging process temperature profile

In this graph, the temperature profile acquisition data is obtained when charging the PCM. The time needed in this study for the sample to freeze was 24 hours. In the PCM 1 sample, the difference in initial temperature to the final temperature was lower than that of PCM 2 and water samples. Where PCM 1 at the 24th hour obtained a temperature of -16.3 °C. Meanwhile, PCM 2 and PCM water have a temperature of -14.7°C and -9°C respectively. This is because there are differences in the composition contained in each sample.

According to Yulita (2016), the speed of the freezing process is one of the factors that can affect the quality of the frozen product to be produced. The freezing speed is affected by the addition of the concentration of salt added to the aci flour solution, the greater the concentration of salt added, the lower the resulting freezing temperature. PCM 1 has a greater salt concentration than PCM 2 so that this affects the freezing point of the PCM 1 sample to be lower. Whereas in PCM water has a composition of 100% water, so the temperature profile is not too low when compared to other PCM samples because considering the freezing point of water, which freezes at 0 °C.

Testing while Discharging

Melting or discharging processes are generally used as cold storage applications. Like cooling the fish caught. According to Irsyad (2021) the increase in temperature during discharging occurs because the PCM absorbs solid sensible heat, latent heat and liquid sensible heat. After a phase change occurs in the PCM, the PCM temperature rises. This increase is due to environmental heat being absorbed into the PCM. The following is a graph of the Discharging Temperature Profile on PCM:

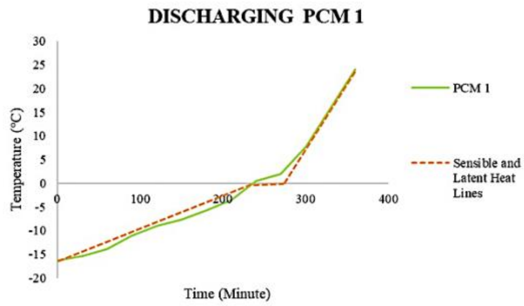

Figure 6. Discharging process temperature profile PCM 1

The results of the temperature profile analysis in the PCM 1 sample discharging process had an initial temperature of -16.3 °C and a final temperature of 24 °C which was obtained in the 360th minute. Where the PCM 1 sample obtained a heat storage of 494.51 kJ/kg.

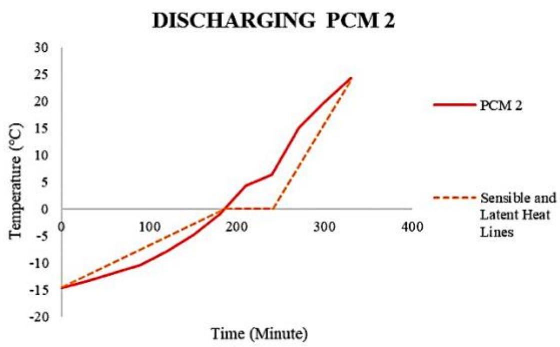

Figure 7. Discharging process temperature profile PCM 2

The results of the temperature profile analysis in the PCM 2 sample discharging process had an initial temperature of -14.7 °C and a final temperature of 24.3°C °C which was obtained in the 330th minute. Where the PCM 2 sample obtained a heat storage of 489.91 kJ/kg.

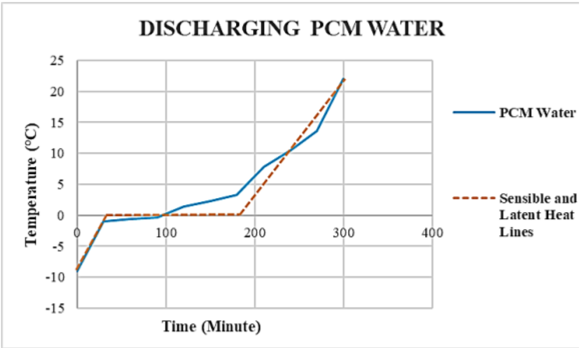

Figure 8. Discharging process temperature profile PCM water

The results of the temperature profile analysis in the PCM water sample discharging process had an initial temperature of -9 °C and a final temperature of 22°C which was obtained in the 300th minute. Where the PCM water sample obtained a heat storage of 463.13 kJ/kg.

From the data above it can be concluded that PCM 1 can maintain temperature longer than other PCMs. In the discharging process an endothermic reaction occurs, namely the PCM sample absorbs heat from the environment into the system. So that the PCM temperature increases.

According to Yulita (2016), the process of liquefaction or decomposition is the process of destroying the crystal structure of a material/substance, which requires heat energy extracted from the material or substance while freezing is the process of reuniting crystals that have been destroyed so that they become solid again. occurs reversibly.

In the discharging process, there is one advantageous factor when using the application of Phase Change Material (PCM). According to Saputro (2018), the heat balance of the system is used to validate fixed conditions and a fixed PCM volume. So that when using discharging, PCM starts to melt. However, the volume on the PCM is still maintained. This is due to the PCM encapsulation method. The PCM encapsulation method is indispensable for PCM applications because it can maintain a fixed volume and act as a solid PCM media or container.

Calculation of Calorific Value

Obtaining temperature profile data can be used to calculate and find out the calorific value required for each sample during the charging and discharging process. The heating value of PCM occurs in 2 phases, namely liquid and solid. This indicates that there are 2 types of heat principles, namely latent heat and sensible heat. calorific value is obtained by the following formula:

$$\boldsymbol{Q_{Total} = Q_{Sensibel} + Q_{Laten}} \text{ ....(3)}$$

Where :

$$Q = m.C_p.\Delta T \text{ .... (4)}$$

Information:

Q = heat energy released/accepted by substance (J)

m = mass of substance (kg)

Cp = specific heat (J/kg.K)

ΔT = temperature change (K)

The latent heat equation of a substance can be written as follows:

$$Q = m.L \text{ .... (5)}$$

Information :

Q = heat energy released/accepted by substance (J)

m= Mass of substance (kg)

L = Latent heat (kJ/kg)

From this equation, the heat storage (Q) of the PCM 1, PCM 2, and water PCM samples was 494.51 kJ/kg; 489.91 kJ/kg; and 463.13 kJ/kg. According to Korawan (2019), in his research a heat storage of 275 kJ/kg was found in PCM from paraffin material. The greater the required Q value, the greater the energy required for the freezing process. Likewise with the melting process, the greater the Q value, the greater the energy that can be absorbed by the PCM sample. So that the application of PCM during the discharging process will occur longer.

According to Farid (2021), there are

other things that can affect the calorific value and performance of PCM including the influence of the characteristics of the PCM material, the properties of PCM have different characters such as a mixture of salt in water which can lower the freezing point of water. The effect of cooling load can also affect how quickly PCM freezes or thaws because it can affect the energy transfer process which takes longer if there is more than 1 material being cooled in one freezer room. Besides that, the influence of the freezer temperature, if the freezer temperature is lower than the freezing point of each sample. Then you will get a more significant temperature drop.

According to Hale (1971), No single PCM material is perfect because no material has all the properties desired for an ideal PCM. PCM is expected to provide isothermal control for a given time in a given application. there has been much effort in choosing the most ideal PCM for a particular application. This material deficiency can be corrected by adding new materials. Such as the addition of metal materials intended to increase the thermal conductivity of PCM, in addition to the addition of nucleating agents for material problems that have high supercooling.

In this study materials such as tapioca flour, salt, water, and Acetic Acid were used. Where each material has its own role that can support this research. Tapioca flour functions as a thickening agent that can form a composite gel structure, this can reduce the leakage of PCM material. According to Rasta (2022), thickening agents can also be used to reduce the degree of phase separation. While water serves as the main component. Salt lowers the melting temperature and has good storage of solids. According to Lubis (2016), Acetic Acid or acetic acid functions as a catalyst for the formation of PCM.

CONCLUSION

Based on the results of this study it can be concluded that differences in the freezing point of PCM material mixtures can be influenced by the selection of each material to be used as a PCM product. As the results obtained in this study, the PCM 1 sample obtained a lower temperature than the PCM 2 and water sample which was -16.3 ℃. These results can be explained that this study using a different composition from conventional PCM or water can obtain a lower sample temperature than water. This is also directly proportional to the discharging process, it was found that during the discharging process the PCM 1 sample maintained a longer temperature than the PCM 2 sample and water. The results obtained are in the form of heat that can be stored. The heating values (Q) of the PCM 1, PCM 2, and water PCM samples were 494.51 kJ/kg; 489.91 kJ/kg; and 463.13 kJ/kg.. The greater the calorific value that can be stored, the greater the cooling energy will be required. However, the results of the discharging process will take longer and be optimal. It can be concluded that PCM with the composition of tapioca flour, salt, water and Acetic Acid is better than conventional PCM or water.

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