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Thermophysical Characteristics of VCO-Soybean Oil Mixture as Phase Change Material (PCM) using T-History Method

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Abstract. Phase change material (PCM) is widely used as thermal storage in various fields. Various successes of implementing PCM have been proven. The use of PCM in some systems can reduce electricity consumption. Energy storage utilizes latent heat of material that is larger than sensible heat. In order for a material to be used as thermal storage, it is necessary to know the thermophysical characteristics of the PCM material. A general method for knowing thermophysical characteristics by using Differential Scanning Calorimeter (DSC). The use of DSC has limitations such as the sample used is too little so that the characteristics of the material produced will be very different compared to using the bulk material. The T-history method has the advantage of using large samples and can be done easily. In this study, the T-history method was used to determine the thermophysical characteristics of the material. PCM used is a mixture of Virgin Coconut Oil (VCO) - soybean oil for the application of thermal storage in air conditioners. The mixture of VCO-soybean oil used is 5% and 20% soybean oil in VCO.

Keywords: T-history method, PCM, thermal storage, air conditioning

1. Introduction

The use of phase change materials (PCM) as thermal energy storage (TES) has been widely used in various fields. Not only for heating applications but also for cooling. The use of TES is intended to save energy and release it when needed. All of these are intended to obtain improved system efficiency.

In some PCM systems, it is stored in containers, integrated with walls, floors and ceilings, and some secondary liquid soluble systems circulate in the system such as the use of ice slurry which also functions as a TES. Irsyad et al. [1] using PCM that integrates into the wall as thermal storage for air conditioning systems. The PCM used is coconut oil which is placed in a container. The surface temperature in the PCM produced is 2 degrees lower than using only standard bricks.

The use of PCM which integrates with ice slurry and circulates into the cooling system has also been successfully applied to the CAPCOM building. The PCM used is a mixture of water and alcohol. This system is used to cool the room in chiller air conditioning. The test results show that energy use for air conditioning in buildings can be reduced by 4% when compared to the use of conventional systems [2].

The PCM energy storage process not only takes place in a sensible manner but also utilizes latent heat from the material. When phase changes occur, the heat that can be stored is also greater. The biggest factor in the selection of PCM is the working temperature of PCM which is the temperature at which the material begins to solidify or melt. Besides that, the amount of heat of fusion is also a determining factor in the selection of the type of PCM used. Other factors that need to be considered in the selection of PCM are specific capacities and high conductivity, stable, non-corrosive, non-toxic, non-flammable, small volume changes when phase changes occur, easily obtained, and inexpensive.

In order for a material to be used as a TES, it is necessary to know the characteristics of the PCM use. Testing of melting temperature, specific heat, and heat of fusion can use various methods. Common methods used are Differential Scanning Calorimetry (DSC), Differential Thermal Analysis (DTA), and Calorimetry Method. Although DSC and DTA are widely used to determine material characteristics, several shortcomings that must be considered are: (1) DSC and DTA only measure small samples (1-10 mg) so that the thermophysical properties can be different when using bulk material; (2) DTA and DSC measurements cannot be done for a large number of samples at once. So that necessary measurement repetition which of course requires time, cost and adjustment of the same treatment for each sample [3].

Testing the thermophysical properties using T-history Method provides several advantages compared to other methods. The sample used is large enough to represent the bulk properties of the material commonly applied to TES. Testing can also be done easily if a data recorder is available. In addition, testing can be carried out for various samples simultaneously. The T-history method was first introduced by Yingping et al. [3] and modified by Hong et al. [4] to increase its accuracy.

Silalahi et al. [5] use coconut oil-based PCM as a TES. Testing the thermophysical properties using the T-history method to determine the specific heat in the solid phase, liquid phase, and heat of fusion of PCM. The test results show that the use of this method produces a heat of fusion value that is close to DSC testing. Hong et al. [6] used the T-history method which was modified to test PCM. The results showed a 4% difference compared to the results obtained using DSC.

In this study, the T-history method was used to determine the thermophysical properties of PCM such as specific heat in the solid phase, liquid phase, and heat of fusion of PCM. The PCM material used is a mixture of Virgin Coconut Oil (VCO) and soybean oil. This mixture is chosen so that the working temperature of PCM matches the working conditions of the air conditioning system. The freezing point of soybean oil is -23 - (-20)ºC [7] while the freezing temperature of VCO is 22ºC [8].

2. T-history Method

T-history method testing uses 2 tubes, one tube contains a PCM sample, and one contains a comparison liquid which usually uses pure water. If the PCM temperature in the tube is uniform at T_0 where T_0 is greater than the melting temperature of PCM; T_m is suddenly inserted into a low-temperature room $T_{\infty,a}$ and PCM cools over time. The temperature is then recorded so that a graph of a decrease in temperature with time is produced as shown in Figure. 1.

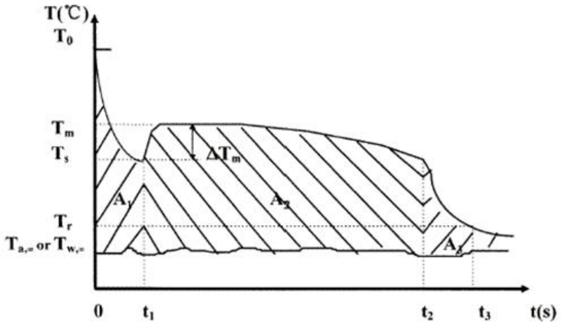

Figure. 1. PCM temperature history with supercooling

Fig. 1 shows the temperature history graph for PCM that has supercooling. The supercooling degree can be determined by the equation $T_m = T_m - T_s$. T_s is a temperature supercooling. The requirement that the T-history method is applied is that the Biot Number that occurs is less than 0.1. Biot numbers are defined as the ratio between convection heat transfer to conduction heat transfer ($Bi = hR/2k$), where h is the convection heat transfer coefficient, R is the tube radius, k is the conduction heat transfer coefficient. When the Bi price is < 0.1, the temperature distribution in the sample can be considered uniform so that the lumped capacitance method can be used [9].

$$m_t c_{p,t} + m_p c_{p,i} (T_0 - T_1) = hA_c A_1 \tag{1}$$

where m_t and m_p are tube mass and PCM, $c_{p,t}$ and $c_{p,l}$ is the specific heat of tube and PCM in liquid phase respectively. A_c is a convection heat transfer area from a tube. The area of heat transfer A_1 can be determined from the equation:

$$A_1 = \int_0^{t_1} (T - T_{\infty,a}) dt \tag{2}$$

The phase change process occurs at $t_1 \rightarrow t_2$. In this area the equation applies:

$$m_p H_m = hA_c A_2 \tag{3}$$

$$A_2 = \int_{t_2}^{t_3} (T - T_{\infty,a}) dt \tag{4}$$

where H_m is the heat of fusion of the PCM, and:

$$m_t c_{p,t} + m_p c_{p,s} (T_s - T_r) = hA_c A_3 \tag{5}$$

where $c_{p,s}$ is the mean specific heats of PCM, and T_r is the reference temperature.

For tubes containing pure water, there is no phase change. The cooling process that takes place simultaneously with the cooling process that occurs in PCM. The process of cooling pure water can be seen in Figure. 2.

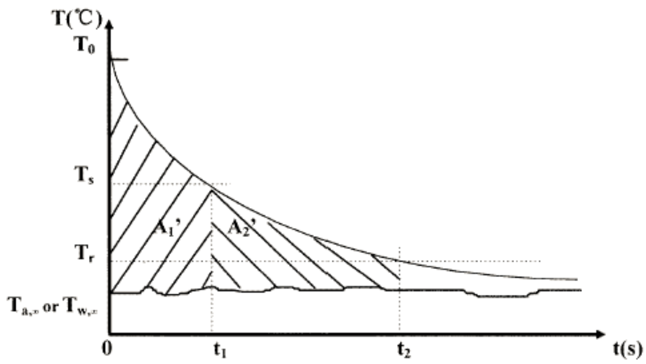

Figure. 2. History of temperature for water

If the Biot Number that occurs in a tube containing water is also < 0.1, then the lumped capacitance method can also be applied the same as the tube containing PCM, so:

$$m_t c_{p,t} + m_w c_{p,w} (T_0 - T_s) = h A_c A'_1 \quad (6)$$

$$m_t c_{p,t} + m_w c_{p,w} (T_s - T_r) = h A_c A'_2 \quad (7)$$

$$A'_1 = \int_0^{t'_1} (T - T_{\infty,a}) dt \quad (8)$$

$$A'_2 = \int_{t'_2}^{t'_3} (T - T_{\infty,a}) dt \quad (9)$$

where m_w is the mass of water, $c_{p,w}$ is the mean specific heat of water. From (1) to (9) it is obtained:

Mean specific heats of the solid PCM:

$$c_{p,s} = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A_3}{A'_2} - \frac{m_t}{m_p} c_{p,t} \quad (10)$$

Mean specific heats of the liquid PCM:

$$c_{p,l} = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A_1}{A'_1} - \frac{m_t}{m_p} c_{p,t} \quad (11)$$

The heat of fusion of PCM:

$$H_m = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A_2}{A'_1} (T_0 - T_s) \quad (12)$$

PCM without supercooling can seen in Figure 3. Then the equation for calculating the heat of fusion is defined from (13), while cp,s and cp,l still use (10) and (11).

$$H_m = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A_2}{A'_1} (T_0 - T_s) - \frac{m_t c_{p,t} (T_{m,1} - T_{m,2})}{m_p} \quad (13)$$

To increase the accuracy of this method, Hong et al. [4] modifying the equation and analyzing the data. The first deficiency of the initial method proposed by Yingping et al. [3] is to use the release point of supercooling as a sign of the end of the phase change. Modification method uses the inflection point as the phase change boundary. The inflection point is determined using the minimum value of the first derivative of the PCM curve. The second disadvantage of the original method is that it does not include sensible heat calculations during the phase change process. Modification of the T-history method will produce an equation:

$$c_{p,l} = \frac{m_{t,w} c_{p,t} + m_w c_{p,w}}{m_p} \frac{A_c}{A'_c} \frac{A_1}{A'_1} - \frac{m_{t,p}}{m_p} c_{p,t} \quad (14)$$

$$c_{p,w} = \frac{m_{t,w} c_{p,t} + m_w c_{p,w}}{m_p} \frac{A_c}{A'_c} \frac{A_3}{A'_3} - \frac{m_{t,p}}{m_p} c_{p,t} \quad (15)$$

$$H_m = -\left(\frac{m_{t,p}}{m_p} c_{p,t} + \frac{c_{p,l} + c_{p,s}}{2} \right) (T_m - T_i) + \frac{m_{t,p} c_{p,t} + m_w c_{p,w}}{m_p} \frac{A_c}{A'_c} \frac{A_2}{A'_2} (T_m - T_i) \quad (16)$$

3. Research Method

This study uses T-history method to determine the thermophysical characteristics of PCM as a TES. The thermophysical properties that will be determined are the mean specific heats of the solid, the mean specific heats of the liquid, and the heat of fusion of PCM. The PCM material used is a mixture of VCO and soybean oil. The composition of the mixture is 5% and 20% soybean oil in VCO based on volume.

The PCM container and the water used are glass tubes with a diameter of 14 mm, the length of the tube is 130 mm, and the thickness of the tube is 1 mm. The temperature measuring instrument used is type K thermocouple. The thermocouple probe has a length of 90 mm and a diameter of 3 mm. to read the temperature data used Labjack U6 data logger. The temperature will be recorded every second. There are 3 thermocouples used which are to measure the temperature of PCM, water and surrounding air. The test diagram scheme is shown in Figure. 3.

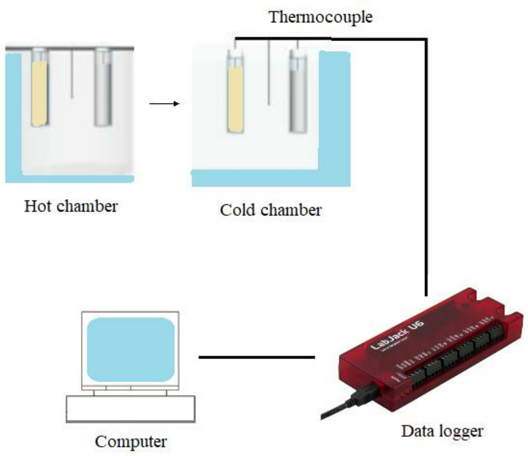

Figure 3. Apparatus diagram scheme

PCM and water in separate tubes were heated in a hot chamber until the initial temperature of T_0 was higher than that of melting temperature (T_m). The two tubes were left for a moment so that the PCM temperature and water were uniform. PCM and water are then put into the cold chamber so that the two tubes will undergo a cooling process. Data temperature against time is then measured by a data logger connected to the computer. A temperature history chart will be obtained for each mixture of PCM, surrounding water and air.

4. Results and Discussion

The research process begins with heating the sample and water in the hot chamber until the temperature of both of them exceeds the melting temperature of PCM. When the temperature is both uniforms, the two samples are inserted into the cold chamber so that the two samples experience a sudden cooling. Three thermocouples are used to measure PCM temperature, surrounding water and air. The three temperature data are the key to calculating the thermophysical characteristics of PCM. The temperature history chart for a mixture of 5% soybean oil in the VCO can be seen in Figure 4.

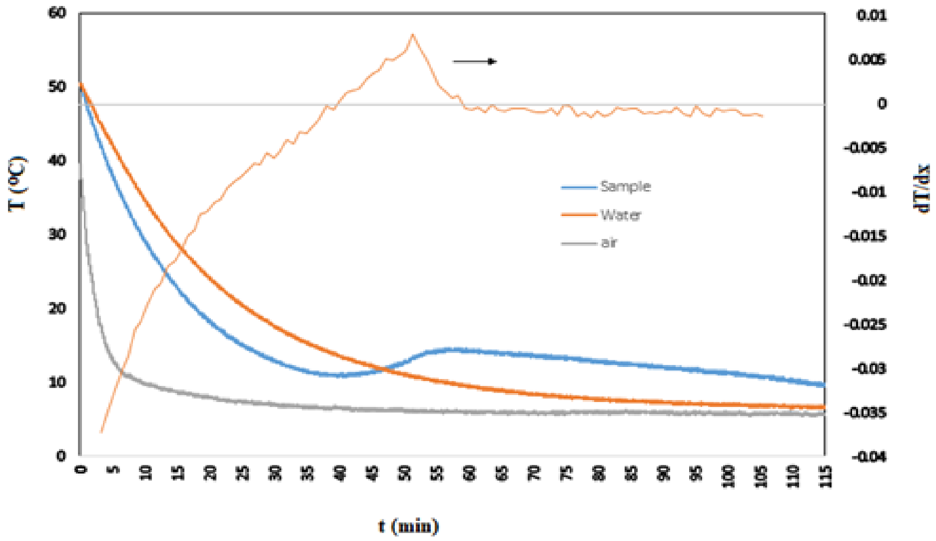

Figure 4. The temperature history for a mixture of 5% soybean oil in VCO

From the graph in Fig. 4, it can be seen that the PCM cooling process will experience a phase change from liquid to solid, while the water will not change phase. The cooling process starts at the initial temperature (T_0) 50.5ºC. The supercooling temperature notated with T_s occurs at 10.8ºC. The solidification temperature notated with T_m occurs at 14.6ºC. The difference between the two temperatures is called supercooling degree is about 3.8ºC.

The same tendency also applies to test 20% soybean oil in VCO as shown in Fig. 5. The curve formed shows that PCM has phase changes while in the water there has been no phase change. Supercooling temperature occurs at 8.1ºC, while temperature solidification occurs at 15.9ºC. Supercooling degree which is formed slightly higher is 7.8ºC when compared to a mixture of 5%.

To determine the boundary for phase change from liquid to solid, then Hong et al. [4] proposed the inflection point as a marker of the end of the transition process. The inflection point is determined as the minimum point of the first derivative of the PCM curve. This is based on the fact that as long as the latent heat release the temperature remains constant, it will decrease exponentially if the energy transfer occurs in sensible heat.

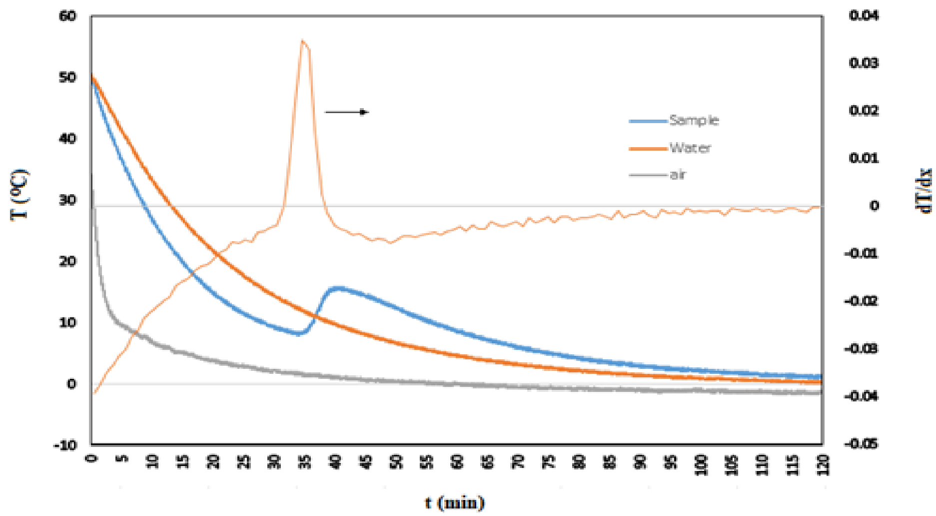

Figure 5. The temperature history for a mixture of 20% soybean oil in VCO

In this way, the inflection point for the 5% mixture can be determined at a temperature of 13.8ºC, which occurs in 69 minutes, while for a mixture of 20%, the inflection point occurs at minute 46 at temperatures of 14.9ºC.

From (14) to (16) the thermophysical characteristics of the mixture can be determined, such as the mean specific heats of the solid, the mean specific heats of the liquid, and the heat of fusion of PCM. The calculation results are tabulated in Table 1.

Table 1. Thermophysical characteristics of VCO-soybean oil mixture

Characteristics	5%	20%
Mean specific heats of the solid PCM [kJ/kg.K]	2.94	2.93
Mean specific heats of the liquid PCM [kJ/kg.K]	6.08	5.63
Heat of fusion of PCM [kJ/kg]	85.30	94.31

The test results showed that the heat of fusion obtained for the mixture was 20% slightly higher than the mixture of 5%. Other results show the potential use of VCO and soybean oil mixtures as TES for cooling system applications, especially for chiller systems, where the latent heat release process occurs between supercooling temperature and temperature solidification, which is in the range of 8.1ºC to 15.9ºC.

5. Conclusion

Determination of the thermophysical characteristics of PCM using the T-history method has been described in this article. The method used is a T-history modification which is proven to be more accurate in determining the boundary for phase change from liquid to solid. The thermophysical characteristics of the mixture are the mean specific heats of the solid, the mean specific heats of the liquid, and the heat of fusion of PCM. The type of PCM used based on organic materials, which is a mixture of VCO and soybean oil. The test results show the potential use as thermal energy storage in the air conditioning system. This is based on the initial temperature of the latent heat release until the end of the phase change process. The mixed heat of fusion obtained was 85.30 kJ/kg for a mixture of 5% and 94.31 kJ/kg for a mixture of 20% soybean oil in VCO.

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References

[1] M. Irsyad, A. D. Pasek, Y. S. Indartono, and A. W. Pratomo, "Heat transfer characteristics of building walls using phase change material," in *IOP Conference Series: Earth and Environmental Science*, 2017, vol. 60, no. 1, p. 12028.

[2] I. Bellas and S. A. Tassou, "Present and future applications of ice slurries," *Int. J. Refrig.*, vol. 28, no. 1, pp. 115–121, 2005.

[3] Z. Yinping and J. Yi, "A simple method, the-history method, of determining the heat of fusion, specific heat and thermal conductivity of phase-change materials," *Meas. Sci. Technol.*, vol. 10, no. 3, p. 201, 1999.

[4] H. Hong, C. H. Park, J. H. Choi, and J. H. Peck, "Improvement of the T-history method to measure the heat of fusion for phase change materials," *Int. J. Air-Conditioning Refrig.*, vol. 11, no. 1, pp. 32–39, 2003.

[5] A. O. Silalahi, N. Sukmawati, I. M. Sutjahja, D. Kurnia, and S. Wonorahardjo, "Thermophysical Parameters of Organic PCM Coconut Oil from T-History Method and Its Potential as Thermal Energy Storage in Indonesia," in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 214, no. 1, p. 12034.

[6] H. Hong, S. K. Kim, and Y.-S. Kim, "Accuracy improvement of a T-history method for measuring the heat of fusion of various materials," *Int. J. Refrig.*, vol. 27, no. 4, pp. 360–366, 2004.
[7] F. Kusnandar, "Mengenal Sifat Minyak dan Lemak, Departemen Ilmu dan Teknologi Pangan," *IPB*, 2010. [Online]. Available: https://habibiezone.files.wordpress.com/2014/04/mengenal-sifat-lemak-dan-minyak.pdf. [Accessed: 25-May-2017].
[8] D. D. Bawalan and K. R. Chapman, "Virgin coconut oil production manual for micro-and village-scale processing," 2006.
[9] T. L. Bergman, F. P. Incropera, D. P. DeWitt, and A. S. Lavine, *Fundamentals of heat and mass transfer*. John Wiley & Sons, 2011.