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HEAT TRANSFER CHARACTERISTICS OF COCONUT OIL AS PHASE CHANGE MATERIALS IN FREEZING PROCESS

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Abstract- The Phase Change Material (PCM) is one of the techniques used to reduce the cooling load of the room. This process is carried out by placing the material at night in the room, releasing heat into the cold air, thereby undergoing a phase change and freezing. Therefore, this research is carried out to determine the heat transfer characteristics of PCM from coconut oil through the surface of the container using two types of materials, namely HDPE plastic and aluminum alloy 1050. The heat transfer layer is located at the top of a cube-shaped container with a side length of 5 cm each and a top surface thickness layer of 1 mm. The results showed that a phase change starts when the PCM is in liquid form and near the surface of the heat transfer layer after releasing heat to the bottom, hence, the part with higher temperature is in the middle. The particles become stationary after the entire PCM has completed the phase change. Furthermore, the lowest and highest temperatures start from the area closest to the heat transfer layer and the bottom, respectively. The freezing process of coconut oil occurs at a temperature of 23-21°C and undergoes sub-cooling to a temperature of 21°C. An increase in flow rate speeds up the super cooling process, especially for PCM near the heat transfer surface with aluminum material. The cooling process in coconut oil PCM done adequately for air velocities of 2.4 and 3.2 m/s at a temperature of 16°C, with the best cooling and heat transfer rates of 0.22°C/min and 3.1 kW/(m^2.kg). The use of aluminum as a layer between PCM and air increases the cooling rate compared to HDPE plastic.

Keywords: Phase Change Material, Paraffin, Coconut Oil, Heat Transfer.

1. INTRODUCTION

Indonesia is a tropical country located on the equator with a high impact on the air temperature during the day, thereby affecting the thermal comfort of the room. The standard of indoor thermal comfort for occupants based on SNI 03-6390-2011 is a dry bulb temperature of 25°C ± 1.5°C with a relative humidity of 60% ± 5% [1]. Therefore, air conditioning machines are needed to obtain thermal comfort in office buildings, hospitals, shopping centers, hotels, education buildings, and residences. However, the use of AC adversely affects the electrical energy consumption in Indonesian buildings with a 65%, 57%, 57%, 55% and 47% consumption rate in commercial buildings, hotels, hospitals, malls, government offices, and office buildings [2]. The increase in energy consumption needs to be balanced with an increase in energy production, especially renewable energy and energy consumption efficiency [3]. Energy efficiency in buildings is very important by considering the maintenance of thermal comfort [4]. Based on data from the Meteorology, Climatology and Geophysics Agency in 2018, the minimum air temperature at night ranges from 17-23°C, which means that it has the ability to cool rooms at night [5].

One of the techniques used to reduce the electrical energy consumption due to the use of AC is by decreasing the cooling load of the room. This process can be achieved by slowing the heat transfer rate into the room through the walls or roof and adding a material capable of absorbing heat. The application of Phase Change Material in buildings is one way to reduce the increase in room temperature. This material is used to store heat energy in the room by absorbing lower ambient air temperature at night, which is emitted during the day, thereby changing from liquid to solid. At the solid phase, the material absorbs heat that enters through the walls or is generated in the room, thereby reducing the thermal load. In this process, the PCM undergoes a phase change from solid to liquid, and by using the high latent heat, the capacity energy absorbed is greater than the material without a phase change.

Several studies showed that the use of Phase Change Materials in buildings positively impacts the thermal conductivity of walls, decreases thermal loads and electricity consumption of air conditioning machines. The use of coconut oil PCM encapsulation in hollow concrete bricks has succeeded in reducing the thermal conductivity by 19.5% and the surface temperature of the inner wall by 3°C [6]. Meanwhile, the use of PCM from composites as a building wall material has reduced the peak cooling load of the room up to 35.4% [7].

The use of coconut oil in the form of microencapsulation as material on building walls can also delay the occurrence of peak loads [8]. Furthermore, the addition of PCM RT27 and SP25 to the wall material in the form of microencapsulation has reduced building energy consumption by 15% [9]. The utilization of Phase Change Material (Micronal from BASF) in the form of microencapsulation on the walls of buildings with awnings has also been able to reduce and slow down the peak temperature by 6% and 36%, respectively [10]. Meanwhile, the mixing of PCM type DS5001 Micronal with Portland cement and gypsum from 5% to 15% in terms of mass fraction has reduced the thermal conductivity of the wall by half [11].

Coconut oil is an organic phase change material made up of fatty acid compounds, such as lauric (C12:0), myristic (C14:0), and palmitic (C16:0) at 49.2%, at 18.9% and 8.9%. These dominant fatty acids significantly affect the PCM phase change temperature because they comprise latent heat and other thermal properties, as shown in Table 1. Several studies found that the freezing temperature of coconut oil is 20°C [12,13]. The thermal properties of coconut oil needed to analyze heat energy storage are shown in Table 2.

Table 1. Fatty acid composition of coconut oils [14]

Fatty acid	Carbon Number	Composition (%)	Melting point (°C)	Latent heat (kJ/kg)
Caproic	C6:0	0.4	n/a	n/a
Caprylic	C8:0	7.3	16 [15]	148.5 [15]
Capric	C10:0	6.5	32.2 [16]	159 [16]
Lauric	C12:0	49.2	45.3 [17]	187.2 [17]
Myristic	C14:0	18.9	55.3 [16]	190 [16]
Palmitic	C16:0	8.9	60.45 [18]	221.42 [19]
Stearic	C18:0	3.0	66.87 [18]	242.15 [19]
Oleic	C18:1	7.5	13-14 [18]	138.07 [19]
Linoleic	C18:2	1.8	(-9)-(-8) [18]	n/a
Linolenic	C18:3	0.1	-17.9 [18]	n/a

Table 2. The thermal properties of coconut oil

Thermal properties	Units	Value
Melting temperature	°C	22-24 [20]
Freezing temperature	°C	18-21 [21]
Latent heat (melting)	kJ/kg	114.6 [22], 103.25 [20]
Latent heat (freezing)	kJ/kg	94.61 [221]
Specific heat capacity (liquid)	kJ/(kg.K)	4.1 [12], 2.1 [20, 23]
Specific heat capacity (solid)	kJ/(kg.K)	3.2 [12], 2.9 [20, 24]
Thermal conductivity (liquid)	W/(m.K)	0.21 [22]
Thermal conductivity (solid)	W/(m.K)	0.261 [22]

2. MATERIAL AND EXPERIMENTS

This is experimental research carried out to determine the heat transfer characteristics of PCM in the box by cold air flowing through the surface with 2 types of materials, namely High-Density Polyethylene (HDPE) plastic and aluminum alloy 1050. The PCM used is coconut oil, while the properties of HDPE and aluminum alloy 1050 are shown in Table 3.

Table 3. Properties of material

Properties	Value	References
HDPE		
Density	0.945 g/cm^3	[25]
Thermal conductivity	0.44 W/mK	[26]
Aluminum alloy 1050		
Density	2710 kg/m^3	[27]
Thermal conductivity	227 W/m.K	[27]

The PCM cooling characteristics test was carried out on the test equipment, as shown in Figure 1. PCM from coconut oil was put into a container with a size of 5×5×5 cm using HDPE plastic and aluminum alloy 1050 as the upper plane materials. Meanwhile, the cold air used to absorb heat comes from the AC evaporator and flows through a channel installed with a honeycomb before the test section. The cold air temperature flowing is 16 °C with varying cold airflow speeds of 1.6, 2.4, and 3.2 m/s. PCM temperature was measured at a distance of 1 cm each, from the top surface to the bottom of the box. Furthermore, the plate surface temperature and cold air were also measured. The heat released by PCM in single-phase and change conditions can be calculated by Equations (1) and (2), as follows [28, 29]:

$$Q_{sensible} = \int_{1}^{2} m \cdot C_p \cdot dT \tag{1}$$

$$Q_{latent} = m_{pcm} \cdot L_{pcm} \tag{2}$$

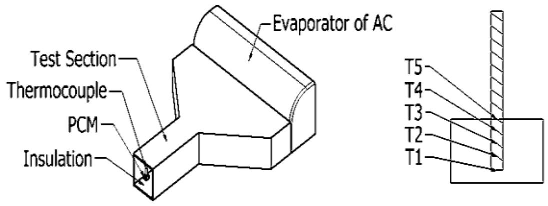
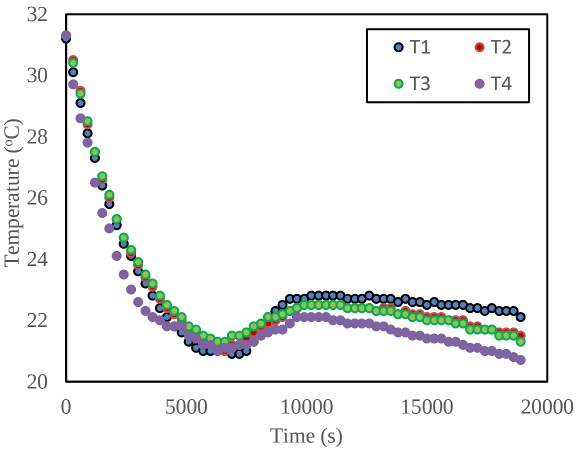


Figure 1. Schema of test equipment

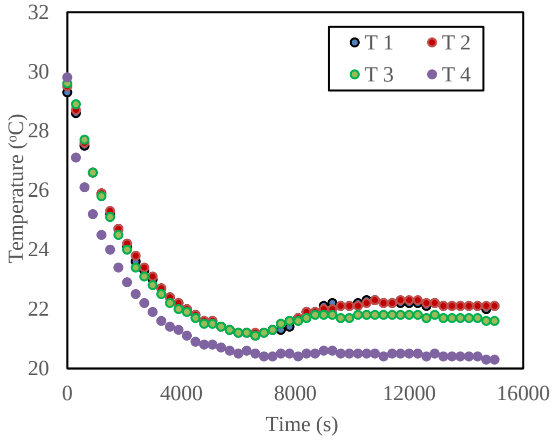
3. RESULTS AND DISCUSSION

Heat is transferred from the PCM through the convection and conduction processes from the top surface of the box, through the material layer. The PCM experiences a decrease in temperature, which leads to an increase in density. Therefore, the heat transfer process is indicated by the temperature change at each point, as shown in Figure 2. During the cooling process, the PCM fluid depreciates after a decrease in temperature. At a single liquid phase, the PCM lowest (T_1) and highest (T_4) temperatures of heat transfer are determined at the surface Meanwhile, in the middle of the PCM, namely T_2 and T_3, the temperature is higher than the 2 parts. Furthermore, after the freezing process, the lowest temperatures are determined from the top to the bottom.

Figure 2b shows the use of aluminum as a heat transfer area to accelerate the process, thereby reducing sub-cooling, even at the point closest to the heat transfer surface.



(a) HDPE



(b) Aluminum alloy 1050

Figure 2. Distribution of coconut oil temperature on the cooling process with heat transfer surface using plastic and Aluminum

The cold airflow affects the cooling rate of the PCM because the faster the rate, the more rapid the sub-cooling and freezing process, as shown in Figure 3. The difference in cooling rate between 1.6 and 2.4 m/s and the rise in speed is significant. The average cooling rates of PCM in the liquid state for each speed were 0.10 °C/min, 0.20 °C/min and 0.22 °C/min. This is similar to the average heat transfer rates of PCM in the liquid state, namely 1.4 kW/(m^{2}kg), 2.8 kW/(m^{2}kg), and 3.1 kW/(m^{2}kg).

The use of an Aluminum heat transfer layer is slightly better than HDPE plastic on PCM, as shown in Figure 4. This is illustrated from the heat transfer and average cooling rates for each layer, namely 3.1 kW/(m^{2}kg) and 2.8 kW/(m^{2}kg) as well as 0.22 °C/min and 0.20 °C/min. The heat transfer in this system is affected by the surface area, thickness, and thermal conductivity of the box layer as well as by the thermal properties of the PCM. These results indicate that the thermal properties of PCM are significantly affected than coating materials because their thickness is only 1 mm.

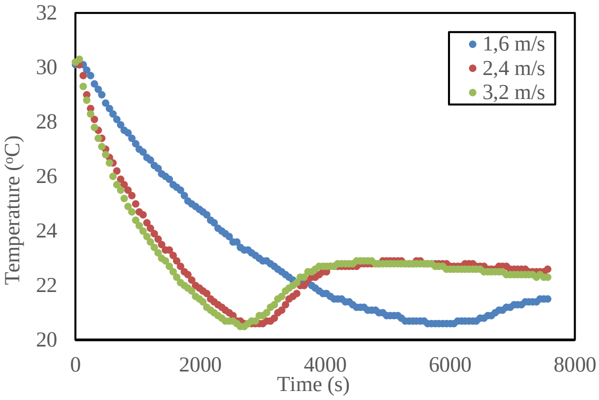


Figure 3. Coconut oil temperature for variations in cold airflow velocity using an Aluminum heat transfer surface in the cooling process

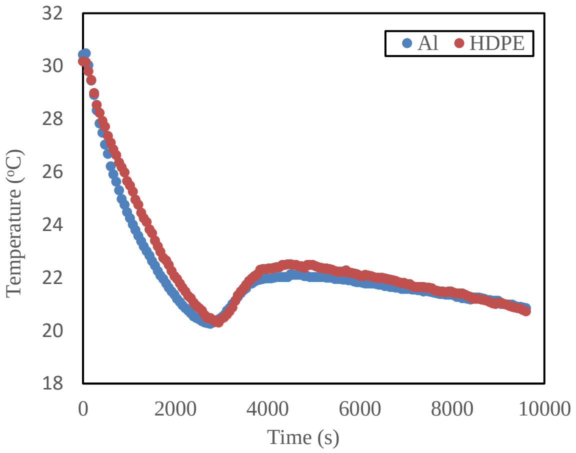


Figure 4. Comparison of coconut oil temperature between use of Aluminum and HDPE plastic heat transfer surfaces in cooling process

4. CONCLUSIONS

In conclusion, the cooling process in coconut oil PCM runs adequately for air velocities of 2.4 and 3.2 m/s at a temperature of 16°C, with the best cooling and heat transfer rates of 0.22 °C/min and 3.1 kW/(m^{2}kg). In the liquid state, the lowest PCM temperature is at the top and bottom, while in the middle, it is higher. The process of freezing coconut oil occurs at a temperature of 23-21 °C. Therefore, increasing the rate of heat transfer reduces the sub-cooling process. Furthermore, the effect of using Aluminum alloy 1050 and HDPE material with a thickness of 1 mm on the cooling rate and heat transfer is not too significant.

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