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Heat transfer characteristics of coconut oil as phase change material to room cooling application

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Abstract. Thermal comfort in a room is one of human needs in the workplace and dwellings, so that the use of air conditioning system in tropical countries is inevitable. This equipment has an impact on the increase of energy consumption. One method of minimizing the energy use is by using the phase change material (PCM) as thermal energy storage. This material utilizes the temperature difference between day and night for the storage and release of thermal energy. PCM development on application as a material for air cooling inlet, partitioning and interior needs to be supported by the study of heat transfer characteristics when PCM absorbs heat from ambient temperature. This study was conducted to determine the heat transfer characteristics on coconut oil as a phase change material. There are three models of experiments performed in this research. Firstly, an experiment was conducted to analyze the time that was needed by material to phase change by varying the temperature. The second experiment analyzed the heat transfer characteristics of air to PCM naturally convection. The third experiment analyzed the forced convection heat transfer on the surface of the PCM container by varying the air velocity. The data of experimental showed that, increasing ambient air temperature resulted in shorter time for phase change. At temperatures of 30°C, the time for phase change of PCM with the thickness of 8 cm was 1700 min, and it was stable at temperatures of 27°C. Increasing air temperature accelerated the phase change in the material. While for the forced convection heat transfer, PCM could reduce the air temperature in the range of 30 to 35°C at about 1 to 2°C, with a velocity of 1-3 m/s.

1. Introduction

The need for electricity in Indonesia increase every year, in which on average the increase each year is 6.6%. The using of electricity is dominated by household sector (41%), industrial sector (34%), and commercial sector (24%) [1]. In commercial sector, the use of AC dominates the use of electrical power at approximately 65% [2]. The same case applies in household sector, that is shown by increase in use of split AC.

What encourages people in using AC is to experience room thermal comfort, either for doing activities, working and for taking a rest. Based on Indonesian National Standard (SNI) 03-6390-2011, room thermal comfort for occupants is at the temperature of 25°C ± 1.5°C and relative humidity of 60% ± 5% [3]. The air temperature condition in Indonesia on average at daytime is higher than the thermal comfort temperature, such as 28-28.5°C in Jakarta, 29°C in Makassar, Surabaya and Yogyakarta [4]. This has caused the use of AC to be the primary need. On the other hand, the difference in daytime and night time temperatures is quite significant. The average minimum temperature at night time is quite low at 22°C, or it could even get lower than 20°C. This potential



may be used to cool room air at daytime by using phase change material (PCM) as storage of thermal energy. Cool air at night time can take the energy from PCM thus phase change takes place. While at daytime, PCM can take the energy from the air which is passed until the phase change takes place again. Compared to one phase material, the energy that could be absorbed by PCM at phase change range is much higher because of using energy in the form of latent heat. The superiority of this PCM high stored energy as well as able to work in low temperature range at its phase change temperature.

The study related to the use of PCM as thermal energy storage for room cooler has been conducted by researchers. There are three forms of PCM application for room cooling: air cooling by channeling into PCM container, as thermal energy storage (TES) to increase efficiency in heating ventilating air conditioning (HVAC) system, and using PCM on wall, floor as well as ceiling, by mixing into the material, or installed in the form of container. Kange et.al. [5,6] conducted a study on the utilization of PCM in which cool air was channeled at night time and room air was circulated at day time known as night ventilation with a PCM packed bed storage (NVP) system. Yamaha et.al. [7] used PCM HVAC system as thermal energy storage, that is used when load condition is at the highest. Indartono et.al. [8] used micro encapsulation phase change material (MPCM), one of the materials in the making of bricks which functions as daytime thermal energy storage. PCM material that has been studied for the application of room cooler is summarized in the Table 1. This study aimed to evaluate characteristics of coconut oil as phase change material to room cooling application.

Table 1. Phase change material to room cooling application.

PCM	Melting temperature (°C)	Heat fussion (kJ/kg)	c _p (kJ/kg.K)	k (W/m.K)	ρ (kg/m ³)	Ref
s19	19	160	1.9	0.43	1520	[9,10]
S21	22	170	2.2	0.54	1530	[9,10]
ClimSel C21	21	144	3.6	0.5	1380	[9,11]
S23	23	175	2.2	0.5	1530	[9,10]
CimSel C24	24	126	3.6	0.5 – 0.7	1380	[9,11]
S25	25	180	2.2	0.54	1530	[9,10]
A22	22	145	2.22	0.18	785	[9,10]
A23	23	145	2.22	0.18	785	[9,10]
A24	24	124	2.22	0.18	790	[9,10]
A25	25	150	2.26	0.18	785	[9,10]
SP 22A17	22 -24	150	-	0.6	1490	[9,12]
Paraffin C13-C24	22 -24	189	2.1	0.21	900	[9,13]
Mystiric acid–Capric acid (34%–66%)	24	147	-	0.164	888	[9,14]

2. Experimental

In this PCM research, Barco brand coconut oil was used. From the initial test, the freezing process took place from the temperature of 24°C. While the melting process took place at the temperatures of 22-24°C. The characteristics of this material from several references are shown in Table 2.

Table 2. Properties of coconut oil.

Density (kg/m ³)	Thermal conductivity (W/m.K)	Melting temperature (°C)	Heat of fusion (kJ/kg)	References
916	=0.62+0.1006*T	22 – 24	103.25	[15]
-	0.321	26.78	110.4	[16]

To determine characteristics of heat transfer at this PCM, three tests were conducted: time of phase change, characteristics of heat transfer when coming in contact with ambient air, and characteristics of heat transfer with forced convection. The schemes of the three test equipment are shown in Figure 1.

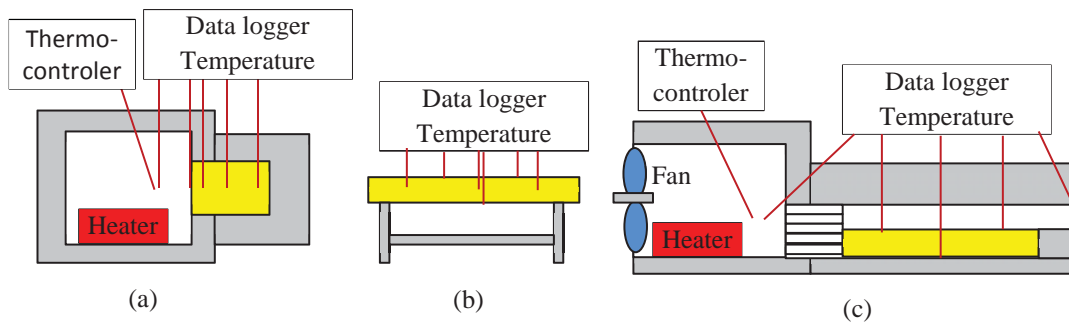


Figure 1. Scheme of test equipment: a) phase change time, b) characteristics of heat transfer with natural convection by the surrounding air, c) characteristics of heat transfer with forced convection.

In the test of melting time, PCM was placed in container of 4 x 6 x 10 cm (Figure 1a). The surface of heat transfer was only found on one side of the surface with the size of 4 x 6 cm, made of aluminum of 0,2 mm in thickness. PCM thickness from the surface of heat transfer was 10 cm. Thermocouple was applied in conditioned air, surface of heat transfer, and at PCM thickness of PCM 1 cm, 5 cm and 9 cm. Hot air was controlled by using a thermo-controller. Data were taken at air temperatures of 30, 40 and 50°C. Data was recorded until the temperature of the PCM was not increased again. At the test of heat transfer with the surrounding air, PCM was placed inside an aluminum profile, with the size of 0.5 x 1 inch and length of 10 cm as shown in Figure 1, section b. Data collecting was started at a PCM temperature of 20°C. Thermocouples were installed on the top and bottom surfaces of PCM location and inside the PCM. Data was recorded until the PCM temperature exceeding the melting temperature. On the other hand, test with forced convection was conducted on one surface of PCM container made of three aluminum profiles with the size of 0.5 x 1 x 10 cm as shown in Figure 1, section c. Air velocity was varied at 1 and 1.5 m/s. Air temperature was varied at 30 and 33°C. Thermocouple was placed on the top and bottom surfaces of the container, also in air before and after test section. Temperature test data was recorded by using temperature data logger Lutron 452SD. The velocity of air flow was measured using anemometer Lutron 22SD.

The result was analyzed for each test. In the first test, time needed for phase change in several air temperature condition was analyzed. In the second test model what was analyzed was the process of phase change by obtaining thermal energy from ambient air. While in the third, test absorption of thermal energy by PCM from accelerated air through convection heat transfer on the surface of PCM container was analyzed.

3. Result and Discussion

Initial study was conducted testing of environmental temperatures at during the day. Measurement did in Bandung city on 18-19 August 2016, in which in the daytime from 9.00 AM-5.00 PM, where the surrounding air temperature exceeded the thermal comfort temperature, as shown in Figure 2.

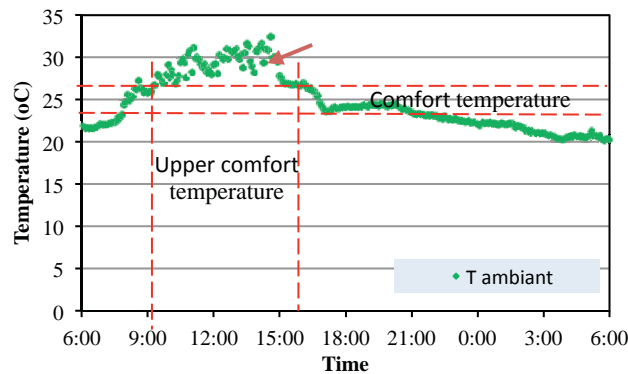


Figure 2. Temperature of ambient air in Bandung on 18-19 August 2016.

The process of PCM melting was started from the part nearest to heat transfer surface. Time of phase change to take place for air temperature of 30°C was quite long starting from 700 min for a distance of 1 cm to 1700 min for a distance of 9 cm from the surface of heat transfer, as shown in Figure 3. One of the causes was that thermal conductivity PCM was not as high compared to water. Besides that also the temperature differences of air and PCM were not too great. A high energy for phase change process also contributed to the time taken for phase change. From Figure 3, sloping curve showed phase change process of PCM at temperatures of 22 to 25°C. Differences in air temperature affected of phase change period as shown in Figure 4. At temperature of 50°C, period of phase change was shorter at 228 min for a distance of 5 cm from heat transfer surface, compared to temperature of 30°C at 1260 min.

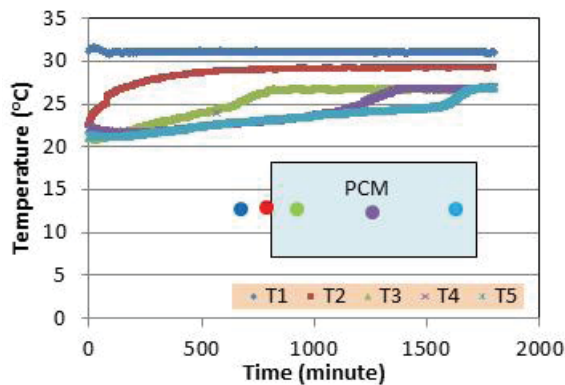


Figure 3. Period of phase change at air temperature of 30°C.

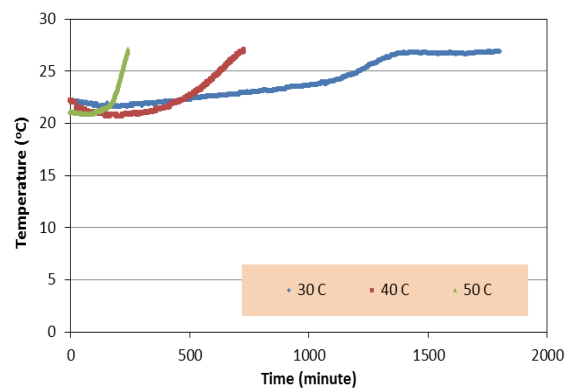


Figure 4. Period of phase change at PCM thickness of 5 cm.

The process of thermal energy absorption from ambient air is shown in Figure 5. At air temperature higher than PCM temperature, heat transfer to PCM took place. The process of phase change took place at the same time as the increase in ambient air temperature. Heat transfer was also caused by radiation heat transfer to surface of PCM container and then continued to the PCM. This was shown starting from the 220 to the 270th min.

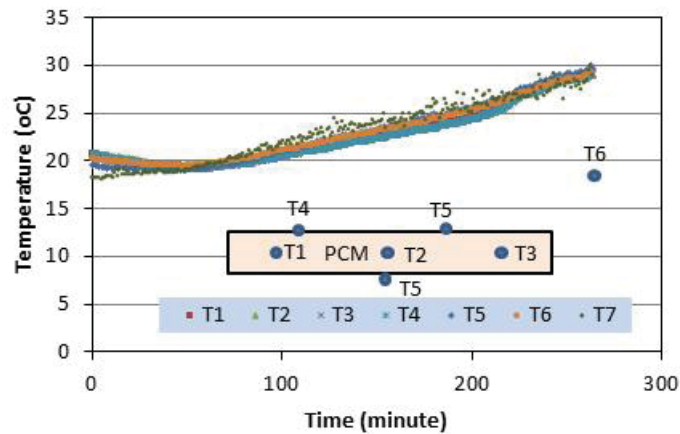


Figure 5. Process of PCM phase change in ambient air.

For forced convection heat transfer, there are two variables tested: air temperature and flow velocity. The process of phase change started from the closest area to incoming air and on the upper side. The process of change moved to the area of air outside and lower part of PCM, as shown in Figure 6. The time for the process of phase change for the entire PCM in the container at the speed of 1m/s and temperature of 30°C was 65 min. Average decrease of temperature was 0.83°C. Thermal energy absorbed from the air was 9.6 kJ. The impact of air velocity and temperature towards reduction of air temperature and time of phase change was shown in Table 3. Increasing the air velocity and temperature difference of air and PCM could increase of reduction of air temperature. Reduction of air temperature was range between 0.83 and 1.29°C. For the application of surrounding air cooling still possible for improve in temperature decrease by increasing flow speed and expanding heat transfer surface.

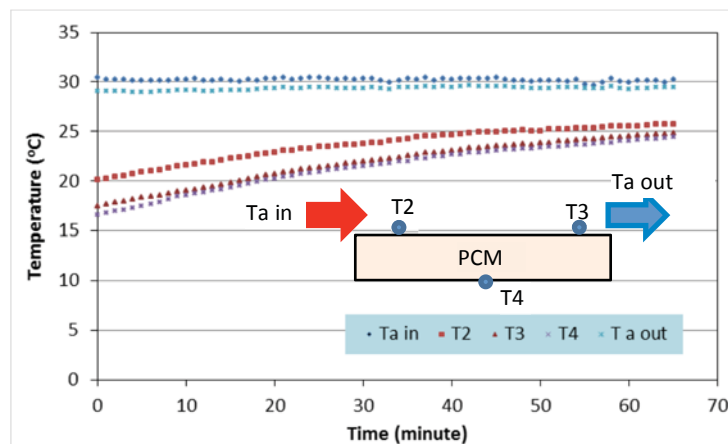


Figure 6. Surrounding air temperature decrease by using PCM.

Table 3. Heat transfer in ambient air using PCM.

Velocity (m/s)	ΔT (°C)	Time (min)	Heat transfer (kJ)	
1.0	30°C	0.83	65	9.58
	33°C	1.19	32	6.60
1.5	30°C	0.82	48	10.24
	33°C	1.29	24	8.05

4. Conclusion

The utilization of PCM with high thermal conductivity needs to consider the thickness of container as it gives an impact on time of phase change. By natural convection heat transfer the time of phase change takes a long time. PCM in container that comes in contact directly to the surrounding air experiences phase change process with the increase in surrounding air temperature. Heat transfer through forced convection on PCM container surface can decrease the ambient temperature of 0.82-1.29°C, with air velocity of 1-1.5 m/s and air temperature of 30-33°C

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