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Heat exchange studies on coconut oil cells as thermal energy storage for room thermal conditioning

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Abstract. As reported by many thermal environment experts, room air conditioning might be controlled by thermal mass system. In this paper we discuss the performance of coconut oil cells as room thermal energy storage. The heat exchange mechanism of coconut oil (CO) which is one of potential organic Phase Change Material (PCM) is studied based on the results of temperature measurements in the perimeter and core parts of cells. We found that the heat exchange performance, i.e. heat absorption and heat release processes of CO cells are dominated by heat conduction in the sensible solid from the higher temperature perimeter part to the lower temperature core part and heat convection during the solid-liquid phase transition and sensible liquid phase. The capability of heat absorption as measured by the reduction of air temperature is not influenced by CO cell size. Besides that, the application of CO as the thermal mass has to be accompanied by air circulation to get the cool sensation of the room's occupants.

1. Introduction

In big cities in Indonesia, the highest electrical energy consumption, i.e. above 50% from the total electrical energy consumption, are in the household and building sectors, and in particular it is used for air conditioning (AC) system [1]. This is related to the fact that Indonesia is a tropical country located around the equator, and thus making relatively high the average air-temperature throughout the year [2]. However, it is already commonly known that the use of AC system have negative impacts both directly to the human and also indirectly to the environment due to production of CO_2 gas that can cause local and global environment warming effects [3].

As a passive strategy to reduce the use of AC system in order to achieve the human comfort temperature in the room, one may use thermal energy storage (TES) system. Based on the change in the medium temperature TES system work based on sensible and latent heat concepts, where in the sensible TES there is a change in medium temperature during heat absorption or heat release while latent TES work at constant temperature [4]. The conventional thermal mass system such as wood, brick and concrete wall that work based on sensible heat storage have relatively low effectiveness related to its heat storage capacity and temperature change during heat absorption or heat release. For that reason, thermal mass system based on phase change material (PCM) offer more advantages due to the fact that PCM show superior heat storage density at temperatures around its phase transition without significant change in its temperature [5]. Among many potential PCM, organic PCM from coconut oil (CO) is very comfort and suitable for application in Indonesia due to its characteristic of human and environmental friendly and its abundant amount. In previous references it have been reported the potential application of CO as the medium of latent thermal mass system, namely assessed from physical parameters [6] and capability to lowering the air temperature [7] or water temperature [8] depending on the environment where CO was placed.

In this paper we study the heat exchange of CO in the solid, solid-liquid, and liquid phases by means of temperature measurements arranged in the core and perimeter parts of the CO, by taking the case of heat absorption process. We argue that since CO has relatively low thermal conductivity, its optimum capability to absorb and release the heat might depend on the cell size. The end part of this paper will show how is the cell size of CO might have the role to the capability for the heat absorption of CO to reduce the air temperature in the thermal chamber.

2. Experiment

The coconut oil (CO) was purchased from local supermarket in Bandung, Indonesia. The measurements were divided into two parts, namely the heat exchange study of CO, and how the effectiveness of CO to absorb the heat is vary by the cell size. For the heat exchange study, large amount of CO was placed in a large cylinder plastic container with diameter of 19.5cm and height of 13cm. The system was equipped with 3 termometers placed in some parts of CO, namely 1 termometer at core and 2 termometer at perimeter, at distance one-third of its diameter. The vertical positions arrangement of termometers are described in table 1.

Table 1. The horizontal and vertical positions of thermometer in the cylinder container.

Thermometer Number	Horizontal position	Distance from bottom (cm)
I	perimeter	11.5
II	core	6.2
III	perimeter	8.8

The overall system was placed in a thermal chamber with its temperature can be regulated for cooling and heating, and that the temperatures of the system are directly monitored during the solidification and melting process. The measurements were repeated for two times and the results show good agreement of the data. Before the measurement, the thermometers were calibrated with the procedure described previously [9].

For the effectiveness study, the CO specimen was placed in some cylindrical containers with different cell size that has the same diameter and height, namely 8×8 cm, 2×12cm and 1×16cm for the same total mass of about 3kgs (table 2). The CO' temperature during heat absorption was monitored by a thermometer placed at the core part of each CO cell. The CO was initially cooled so that its temperature is about 10°C. For this measurement, the heater system in the thermal chamber was turned on so that the air temperature reaches the value higher than 45°C before turned off. The effect of CO was studied by two kinds of air temperature measurement: dry bulb thermometer (DBT) and wet bulb thermometer (WBT). While the DBT represent the normal air temperature, the difference between them is used to represent the relative humidity of the environment.

Table 2. The number of CO cell, cell size, and mass of each CO cell for the effectiveness study.

Cell size (cm)	The number of CO cell	Mass of each CO cell (kg)
8	8	0.37
12	2	1.46
16	1	2.96

3. Results and Discussion

The result for heat absorption of CO or equivalently the melting process is described in figure 1. Start from low temperature solid phase, the heat absorption is dominated by sensible heat (phase I) as shown by rather large temperature change. In this region, the temperature value shown by thermometer I show the highest value due to the fact that it is closer to the air environment as the heat source, followed by thermometer III and thermometer II. As the fact, the temperature value shown by thermometer II which is deepest in vertical position initially constant before rising with the time. We argue that the heat exchange is dominated by heat conduction directed vertically rather than horizontally, due to the fact that the plastic container might block the heat from environment to PCM CO.

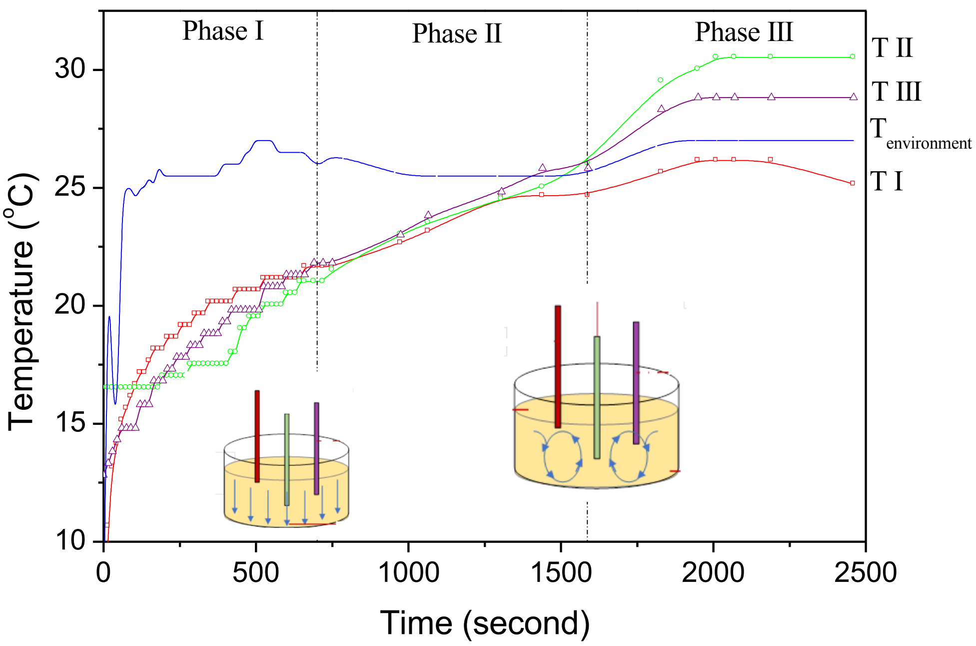

Figure 1. The temperature-time dependent of heat absorption of PCM coconut oil (CO) during melting process, with the position of thermometer I, II and III are described in table 1. The phase regions are described based on the temperature profiles from each thermometer. The inset show the heat exchange process at each phase.

The next region is the latent heat related to solid-liquid phase transition (phase II). Theoretically, this process occur at a constant temperature. However, due to the fact that CO consist of many kinds of fatty acids with more than 50% lauric acid, the solid-liquid phase transition occur with the relatively small temperature change. During this process, the temperature values shown by all thermometers almost the same. Following latent heat absorption is sensible liquid (phase III) characterized with temperature increase upto higher than air temperature for termometer II and thermometer III that are far from the CO'surface as the border between air environment and PCM CO. As the matter of fact, at this two phases, the thermometer I always show the lowest value compared with those of thermometer II and III, which have the values alternately. It seems that CO with characteristic of low thermal conductivity have the property of storing the heat, and once stored the accumulated heat will concentrated at the core and deepest part of CO (part around thermometer II). The heat exchange for this two phases is convective heat (as shown in the lower part of figure 1) with the horizontal component is contribution from the heat exchange through the plastic container.

The results for effectiveness study of CO is described in figure 2 and figure 3. From figure 2 one can see that the air temperature as measured by dry bulb thermometer (DBT) is almost the same for the CO with different cell size, as long as the total amounts of CO are the same. Moreover, by adding the CO, the air temperature decrease by the value of about 3°C compared with those without CO. An interesting fact is that although the effectiveness of CO is not depend on the cell size, the melting process of CO are not the same for different CO cell size. Qualitatively, we found that for CO with smallest cell size, after 4 hours heat absorption process, all part of CO have become liquid, while larger amount of CO mass can sustain up to 7 hours heat absorption, with medium cell size become melted up to 70% and largest cell size become melted up to 20%.

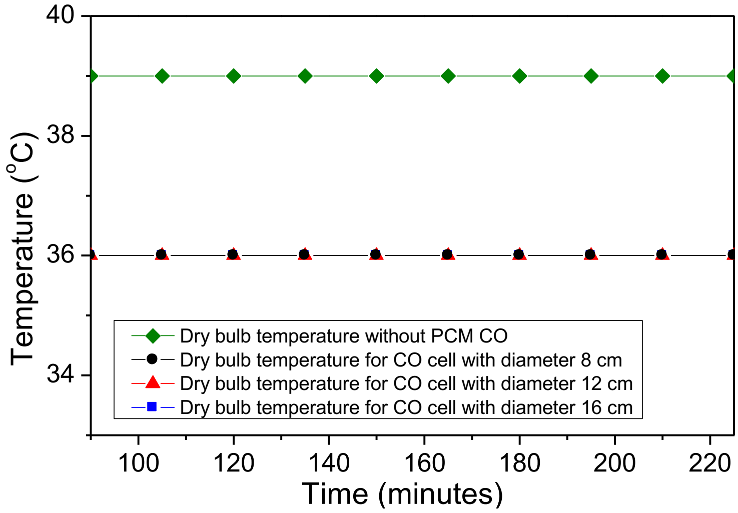

Figure 2. The decrease of air temperature (DBT) in the termal chamber as the effect of CO with varying cell size of cylinder with 8cm, 12cm and 16cm, and the same total mass of about 3kgs.

In difference with the values for dry bulb thermometer (DBT), the values of wet bulb thermometer (WBT) as shown in figure 3 show almost the same values for thermal chamber filled by PCM CO with different cells and for the thermal chamber without any PCM CO. This means that there is no change of the relative humidity of the stable air temperature condition both before and after CO work working on a thermal chamber that is not ventilated. This is in difference with aircond (AC) system that work based on air exchange that cause significant change in the relative air humidity due to that system.

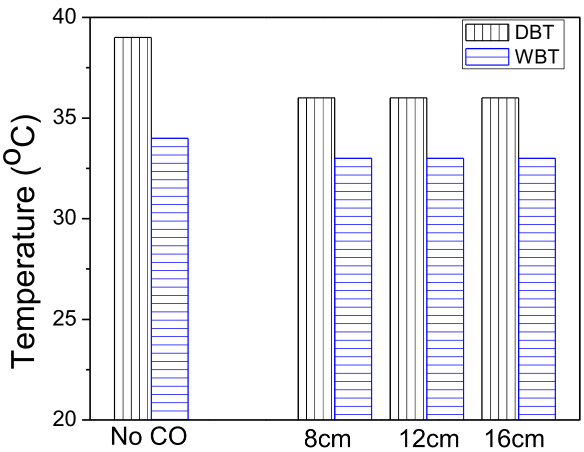

Figure 3. The air temperature as measured by dry bulb thermometer (DBT) and wet bulb thermometer (WBT) in the thermal chamber, without PCM CO and with PCM CO for different cylinder cell size of 8cm, 12cm, and 16cm.

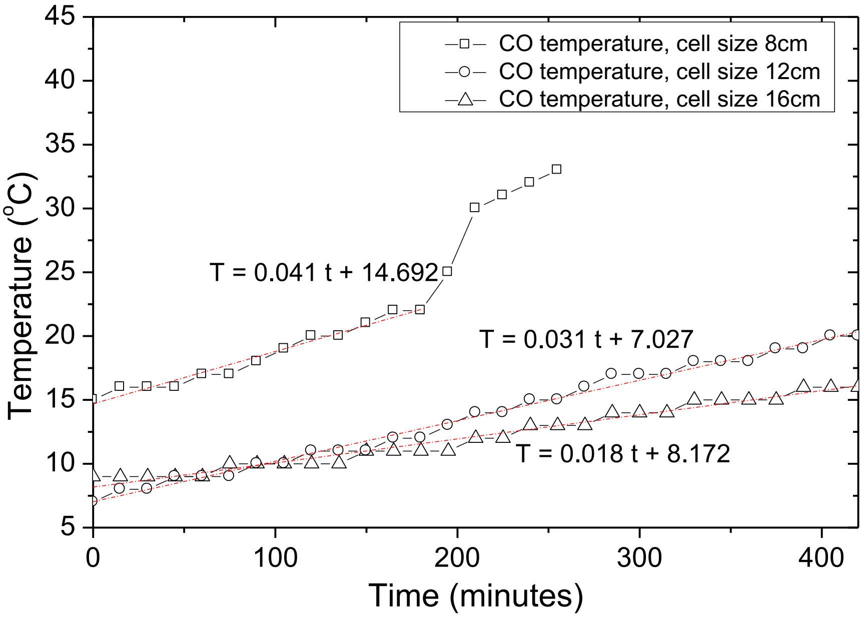

Figure 4. Temperature profiles of PCM CO at various sizes cell during the process of heat absorption in the thermal chamber. The equations show the linear fitting of the data for each CO cell.

The rate for heat absorption of CO at various sizes of cell is shown in figure 4. For 8cm CO cell, the data was taken during the time duration shorter than the others (4 hours) due to the fact that during this time interval all part of CO was melted. No clear signature for the solid-liquid phase transition might be due to high power radiation of heating for this small CO cell. For larger CO cells, namely 12cm and 16cm, for total time duration of 7hours the temperature respons of CO show linier trend with respect to the time. Fitting the linear part of the temperature rising by the time one can see that smaller CO cell have resulted in the larger slope, which might be related to the larger heat absorption rate.

4. Conclusion

We have described in this paper the heat exchange process of organic phase change material (PCM) coconut oil (CO) from the measurement of temperatures in several parts of CO during the heat absorption (melting) process. In the sensible solid, the heat exchange is dominated by heat conduction from high temperature to low temperature. During the solid-liquid phase transition and in the sensible liquid, the heat exchange is convective cooling. The solid-liquid phase transition of CO does not occur at a constant temperature, which might be due to the fact that CO consist of many kinds of fatty acid, with the largest amount of lauric acid (about 50%). With this property, CO behaves as sensible as well as latent heat energy storages. Intensive study to increase the effectiveness of heat exchange between CO and air environment through the cell size variation showed almost no significant results although it is known that CO has relatively low thermal conductivity. This suggests that the role of thermal conductivity in CO may be replaced by heat propagation through convection in the solid-liquid and liquid phases. On the application of air conditioning using thermal mass, there is no decrease in the air humidity, and therefore to get a cool sensation of the occupants, the use of thermal mass have to be followed by the air circulation degenerated from fan or ventilation opening.

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