Thermophysical parameters of coconut oil and its potential application as the thermal energy storage system in Indonesia

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Abstract. The high consumption of electric energy for room air conditioning (AC) system in Indonesia has driven the research of potential thermal energy storage system as a passive temperature controller. The application of coconut oil (CO) as the potential candidate for this purpose has been motivated since its working temperature just around the human thermal comfort zone in the tropical area as Indonesia. In this research we report the time-dependent temperature data of CO, which is adopting the T-history method. The analysis of the data revealed a set of thermophysical parameters, consist of the mean specific heats of the solid and liquid, as well as the latent heat of fusion for the phase change transition. The performance of CO to decrease the air temperature was measured in the thermal chamber. From the results it is shown that the latent phase of CO related to the solid-liquid phase transition show the highest capability in heat absorption, directly showing the potential application of CO as thermal energy storage system in Indonesia.

1. Introduction

In big cities in Indonesia, the highest electrical energy consumption, with the value above 50% from the total electrical energy consumption, is in the household sector and building, and in particular it is used in air conditioning 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. However, it is already commonly known that the use of AC system have negative impacts both directly to the human health and to the environment. This is due to the fact that the use of AC system indirectly produces CO_2 gas that adds local and global environment warming effects. As a passive strategy to reduce the use of AC system, one may use thermal energy storage (TES) system to achieve the thermal comfort condition in the room. TES system works based on sensible and latent heat concepts. Thermal energy capacity storage in the sensible TES is proportional to the heat capacity and temperature change of the material according to $Q_S = mc\Delta T$. In other hand, latent TES is determined from $Q_L = m\Delta H$, where ΔH is the value of latent heat of fusion for solid-liquid phase transition [2,3].

For that application, phase change material (PCM) as the latent TES offer many advantages compared with conventional sensible TES such as concrete and water. This is due to the fact that PCM show superior storage density at temperatures around its phase transition without significant change in its temperature [4,5]. Among many potential PCM, organic PCM from coconut oil (CO) is very suitable for application in Indonesia as the tropical country, due to its abundant amount. Besides that, the results of previous study for thermal characteristic of CO based on Differential Scanning

Calorimetry (DSC) data show the large peak in the charging process indicating the large heat absorption during the solid-liquid phase transition [6]. In this paper we show the results of thermophysical characteristics of CO, consist of the mean specific heats of the solid and liquid, as well as the latent heat of fusion for the phase change transition, by means of T-history method [7]. Compared with DSC, the T-history method offers some advantages, such as the cheaper cost, the use of relatively large amount of the sample give more reliable the physical state of the bulk materials and the possibility to measure the thermophysical parameters of several PCM samples simultaneously.

The principal measurement of the T-history method is to observe the time dependent temperature data of the PCM sample during its heat release or solidification process and compared them with the reference sample (such as water). Following Yinping et al. [7] who firstly introduce this method, and assuming uniform distribution temperature in the sample, i.e. it can be guaranteed when the Biot number, Bi (= $hR/(2\kappa)$, where R is the radius of a tube, κ the thermal conductivity of PCM and h the natural convective heat-transfer coefficient of air outside a tube, is less than 0.1, the mean specific heats of the solid (s) and liquid (l) PCM can be determined based on lumped capacitance method using the following formula:

$$c_{p,s} = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A_3}{A_2'} - \frac{m_t}{m_p} c_{p,t} \tag{1}$$

$$c_{p,l} = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A_1}{A_1'} - \frac{m_t}{m_p} c_{p,t} \tag{2}$$

Besides that, the heat of fusion during the solid-liquid phase change process is determined according to

$$\Delta H = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_t} \frac{A_2}{A_1'} \left(T_0 - T_s\right) \tag{3}$$

In that above formula, the m_w, m_t, m_p are the mass of water, tube and PCM sample; $c_{p,w}$ and $c_{p,t}$ are the heat capacity of the water and the tube; while T_0 and T_s are the initial temperature of the measurement and supercooling temperature of the PCM sample. The parameters area associated with PCM material are: $A_1 = \int_0^{t_1} (T - T_{\infty,a}) \mathrm{d}t$, $A_2 = \int_{t_1}^{t_2} (T - T_{\infty,a}) \mathrm{d}t$, where $t_1 \rightarrow t_2$ is the time interval for the phase change process, and $A_3 = \int_{t_2}^{t_3} (T - T_{\infty,a}) \mathrm{d}t$. In other side, parameter area associated with the reference material (water) is: $A_1' = \int_0^{t_1'} (T - T_{\infty,a}) \mathrm{d}t$ and $A_2' = \int_{t_1}^{t_2'} (T - T_{\infty,a}) \mathrm{d}t$.

To study the potential application of CO as the medium in the TES system, we measured its heat absorption performance using a thermal chamber, and estimate the capability of sensible solid phase, latent phase, and sensible liquid phase for heat storing process. We note that the CO mainly consists of saturated fatty acids, with the highest composition is lauric acid [8]. The potential application of various fatty acids as part of building materials has been reported previously by Chuah et. al. [9]. In particular, Mettawee et. al. [10,11] has reported that the use of CO in the specific country of Sudan and for application in the ceiling system they have reported the peak load shifting time around 2 hours and the decrease of the room temperature between 7-10°C [11].

2. Methods

The commercial trademark of Coconut oil (CO) was purchased from a local supermarket in Bandung, Indonesia. For the thermophysical parameters using T-history method [7], two tubes each contain water and liquid CO as PCM whose temperature is uniform and equal to T_0 ($T_0 > T_m$, T_m is the melting temperature of the PCM) is suddenly exposed to an atmosphere whose temperature is $T_{\infty,a}$ (which can be time dependent). The time dependency of temperature for the water and PCM sample are then recorded manually using the conventional thermometer and the time interval of 2 minutes. Figure 1 show the photographs of the experimental apparatus, consist of liquid specimen of CO, specimens in the water bath, and solid specimen of CO after the measurement.

(a) (b) (c)

Figure 1. (a) Liquid specimen of CO, (b) CO and water as the reference in water bath, and (c) solid specimen of CO.

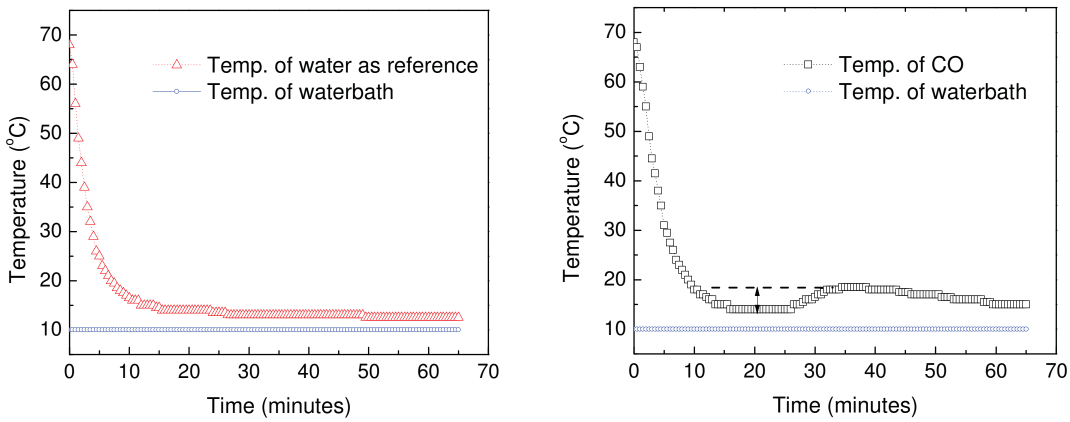
To study the potential application of CO as latent TES, the specimen was placed in a thermal chamber (TC), as shown at figure 2. This chamber with volume of 0.64 m^3 was built with high insulation wall materials of double layer cement 6 mm board with 20 mm Styrofoam in between. The internal sides of this chamber covered with aluminum foil. With those materials specifications the chamber performs as an adiabatic room that can protect the room from influence of external air temperature fluctuation.

Figure 2. Thermal chamber and testing the CO as temperature controller.

In this chamber the effect of solid CO in cells to decreases air temperature were measured. Firstly, the air temperature in the TC was heated by 100 W of a bulb lamp. Secondly, a certain amount of CO in 8 cm cube cell (4 × 8 cm of cube cell) or equivalent to 2 kgs was placed in the TC. For each case, time-dependent air temperature was measured every 5 minutes using conventional thermometer. Besides that, one cube cell of CO was also equipped with a thermometer to study its temperature change during heat absorption process.

3. Results and discussion

The data for the solidification process of CO and water are shown in figure 3. From that figure one can see that the CO undergo the supercooling during the solidification, with the supercooling degree is about 5°C.



(a) (b)

Figure 3. Temperature-history curve during cooling for water (a) and PCM CO (b). The arrow indicates the supercooling degree.

The thermophysical parameters of PCM CO obtained from analysis of the data using Equation (1)-(3) are shown in table 1 together with the values obtained from the previous report.

Table 1. The values of $c_{p,s}$, $c_{p,l}$, and H_m of PCM CO based on analysis of the experimental data and its comparison with the related values from previous references.

	Experimental	References
Mean specific heat of the solid ($c_{p,s}$)	3.2 kJ/kg.K	~ 2.9 J/kg.K [10-11]
Mean specific heat of the liquid ($c_{p,l}$)	4.1 kJ/kg.K	~ 2.1 kJ/kg.K [11-12]
Heat of fusion (H_m)	249 kJ/kg	103 kJ/kg [6], 198 kJ/kg [10]

From this table one can see that the thermophysical parameter values obtained from this experimental data analysis are larger than the values obtained from references. This is perhaps due to the relatively large uncertainty in the temperature data (ΔT) or inhomogeneous temperature distribution of the CO due to its bad thermal conductivity [6].

The potential application of CO as latent TES was shown by the data in figure 4 (a). From that figure one can see that without CO as PCM, the air temperature reaches a stable value of about 37°C after around 1 hour. We note that this temperature value represent the highest temperature at the tropical countries in the afternoon [13]. By inserting the CO, the stable air temperature is decreased to the value of about 35°C after the same time. Thus, the CO as the latent TES has the impact of decreasing the air temperature around 2°C.

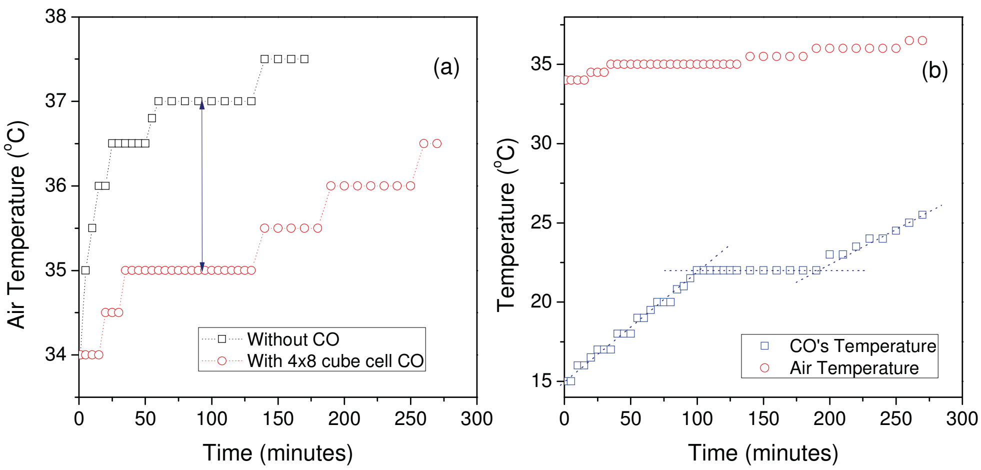


Figure 4. (a) The air temperature without and with CO as the PCM. The arrow indicates the decrease in air temperature due to CO. (b) The air and CO's temperatures. The dotted lines indicate the fitting for sensible solid phase, latent phase and sensible liquid phase of CO.

To study the performance for heat absorption of CO in the above experiment, we calculate the heat absorption capability based on the time-dependent temperature data of the specimen, as shown in figure 4 (b). Using the previous thermophysical parameters from reference (table 1), one might obtained the heat absorption composition in the sensible solid, latent, and sensible liquid phases each are 15%, 80% and 5%. Thus, the results of this kind of experiment directly show the potential application of CO as the medium in TES system.

4. Conclusion

In this paper we have presented the results of the thermophysical characteristics of coconut oil adopting the T-history method. The data has led to the thermophysical parameters; consist of the solidification temperature, the supercooling temperature, the mean specific heat and the latent heat. The results revealed higher values compared with the references, which perhaps due to relatively large uncertainty in temperature measurement. Using the thermal chamber with volume 0.64m^3 as the conditioning air temperature, we have shown the performance of CO to decrease the air temperature by the order of 2°C for 2 kgs CO due to relatively large capability of latent phase or solid-liquid phase transition in storing the heat. With large production of CO in Indonesia as the tropical country, the use of CO as the medium in the thermal energy storage is very suitable and potential to shift the peak hours in electrical energy consumption and to reduce the cooling by the the use of air conditioning system for future energy conservation.

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References

[1] Kementrian ESDM 2015 (Indonesia Energy Outlook 2014) (http://www.esdm.go.id/)

[2] Dinçer Ibrahim and Rosen Marc A 2011 *Thermal Energy Storage: Systems and Applications* (Canada: John Wiley & Sons)
[3] Paksoy Halime Ö 2007 *Thermal Energy Storage for Sustainable Energy Consumption* Nato Science Series II (Netherlands: Springer)
[4] Mehling Harald and Cabeza Luisa F 2008 *Heat and Cold Storage with PCM: an Up to Date Introduction Into Basics and Applications* (Germany: Springer)
[5] Sharma A, Tyagi V V, Chen C R, and Buddhi D 2009 Review on thermal energy storage with phase change materials and applications *Renewable and Sustainable Energy Reviews* **13** p 318-45
[6] Tipvarakarnkoon Tatsawan, Blochwitz Reinhard and Senge Bernhard 2008 Rheological properties and phase change behaviors of coconut fats and oils *Annual Transactions of the Nordic Rheology Society* **16**
[7] Zhang Yinping, Jiang Yi and Jiang Yi 1999 *A* simple method, the T–history method, of determining the heat of fusion, specific heat and thermal conductivity of phase change materials *Meas. Sci. Tech.* **10** p 201–205
[8] Gopala Krishna A G, Gaurav Raj, Ajit Singh Bhatnagar, Prasanth Kumar P K and Preeti Chandrashekar 2010 Coconut oil: chemistry, production and its applications-a review *Indian Coconut Journal* 7**3** p 15-27
[9] Chuah T G, Rozanna D, Salmiah A, Thomas Choong S Y, and Sa'ari M 2006 *Fatty Acids used as Phase Change Materials (PCMs) for Thermal Energy Storage in Building Material Applications* (Malaysia: Jurutera) p 8-15
[10] Mettawee E S, Eid E I and Amin S A M 2012 Experimental study on space cooling with pcm thermal storage *Journal of Applied Sciences Research* **8** p 3424-32
[11] Mettawee E S and Ead A I 2013 Energy saving in building with latent heat storage *Int. J. of Thermal & Environmental Engineering* **5** p 21-30
[12] Tochitani Yoshiro and Fujimoto Masanori 2001 *Measurement of Specific Heat Capacity of Vegetable Oils* (Japan: Netsu Bussei) **15** p 230-36
[13] Koenigsberger O H, Ingersoll T G, Mayhew A and Szokolay S V 1974 *Manual of Tropical Housing and Building* (London: Longman) p 320