The effectiveness of organic PCM based on lauric acid from coconut oil and inorganic PCM based on salt hydrate $CaCl_2.6H_2o$ as latent heat energy storage system in Indonesia

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Abstract. A latent heat energy storage system utilizing phase change materials (PCM) is an alternative strategy to reduce the use of Air Conditioning (AC) system in big cities in Indonesia in order for energy conservation in the future. In this research we used two kinds of materials, namely organic PCM based on lauric acid from coconut oil (CO) and inorganic PCM based on salt hydrate $CaCl_2.6H_2O$, because they have thermophysical parameters suitable for human's thermal comfort application in the building. The CO which contained more than 50% lauric acid has the melting temperature (T_m) of about 26 °C and heat entalphy (ΔH) around 103 kJ/kg, while $CaCl_2.6H_2O$ has the melting point of 29 °C and heat entalphy of 190 kJ/kg. In this paper we report the effectiveness of those two kinds of PCM in reducing the air temperature as one of some criteria for human's thermal comfort. The experiments were performed in a close and adiabatic room and the time-temperature measurements were done automatically using Arduino microcontroller and LM35 temperature sensor connected to the PC.

1. Introduction

The relatively high air temperature during the day in big cities in tropical countries such as Indonesia has encouraged the use of electrical energy for air conditioning system. Data from the Ministry of Energy and Mineral Resources of Indonesia shows that electrical energy consumption for AC system is the largest of the total electrical energy consumption [1]. So far, the electrical energy source that is mostly taken from nonrenewable energy sources such as fossil fuels. Limitations on the use of this energy source strongly require the use of alternative energy sources for the purpose of energy conservation in the future.

For the room temperature conditioning application, one alternative method is the use of thermal energy storage (TES) system. The heat storage capacity for the sensible TES system depend on the heat capacity and temperature change of the material, namely $\Delta Q = mc\Delta T$. In other side, the amount of heat stored in the latent TES is determined by $\Delta Q = m\Delta h$, where Δh is latent heat of fusion for solid-liquid phase transition. This later system use phase change materials (PCM) as the medium of heat storage through the solid-liquid phase change [2-5]. During the day until afternoon, the absorbed heat from the environment is stored as the latent heat to break the chemical bonding of the molecules and it is associated as the melting process. On the other hand, during the night until early morning

PCM restore the heat that has been absorbed to the environment to increase the air temperatures that are commonly low, and it is associated as the solidification process. Thus, PCM can be used fully as the temperature controller system as a part of building component to achieve the human thermal comfort [3-5].

Among many PCM, organic PCM from coconut oil and inorganic PCM based on salt hydrate $CaCl_2.6H_2O$ are the appropriate materials for this particular application in the tropical area because they have suitable thermophysical parameters, in particular its melting temperature around human thermal comfort zone [6]. In the tropical countries such as Indonesia the use of coconut oil (CO) as organic PCM is also a proper choice due to relatively large amount of its availability. We note that the use of CO as the latent TES to control the room air temperature has been reported previously by Mettawee et al., in specific country of Sudan [7]. Figure 1 show the comparison for the estimated amount of heat energy storing capability of CO and $CaCl_2.6H_2O$ as medium in the latent TES system compared with those of water as medium in the sensible TES in the temperature range of 20-35ºC [8].

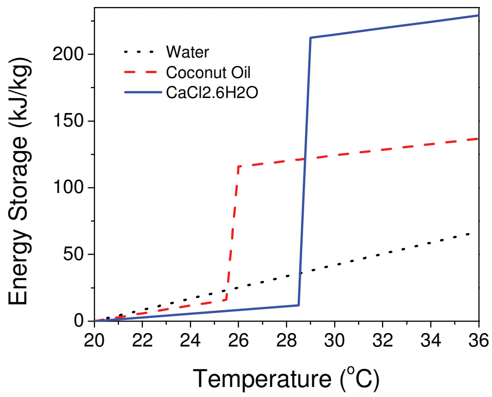

Figure 1. The estimated amount of thermal energy storing capability of CO and $CaCl_2.6H_2O$ as the organic and inorganic PCM and its comparison with water systems that only store/release the sensible heat in the investigated temperature range. Adapted from [8].

2. Methods

Materials used in these experiments are coconut oil (CO) and calcium chloride hexahydrate ($CaCl_2.6H_2O$). A commercial brand of coconut oil was purchased from a local supermarket in Bandung, Indonesia. It is to be noted that coconut oil consist primarily of several kinds of saturated fatty acid, and the highest composition is lauric acid (> 50%). In other side, $CaCl_2.6H_2O$ was provided from Sigma Aldrich with purity better than 98%.

The experiments focused on the heat absorption (melting) of the system: coconut oil, calcium chloride hexahydrate as PCM and water as reference. Instead of air, water was used as the medium of the environment, to avoid the temperature fluctuation during the measurement. Hence, about 2 litters of water were surrounded by an adiabatic wall to prevent the influence of the outside air environment. The initial temperature of the water environment is about 28ºC. At the first series of experiments, water as the system with amounts of about 250 gr and initial temperature below 15°C was placed in a thin plastic container and equipped with a temperature sensor made of LM35. The sample is then inserted into the water environment, so that the heat exchange was occur between the system and environment; their temperature changes are recorded with a time interval of 5 s and the measurement were performed until the equilibrium state was achieved. The measurement with water system was also intended to estimate the amount of absorbed heat by the adiabatic container. At the next series of experiments, water as the system was replaced by CO and $CaCl_2.6H_2O$ as the PCM. All the temperature measurements were done automatically using arduino based program that connected to the PC. Figure 2 shows the photograph of the experimental setup.

Figure 2. Photograph of the experimental setup for measuring the effectiveness of water as the sensible TES as well as CO and $CaCl_2.6H_2O$ as the latent TES.

3. Results and discussion

Because the system and environment are at different initial condition, namely their temperatures are different, the heat exchanged occurs as observed from their temperature change. Taken into account that the solid-liquid phase transition is involving the first-order and second-order phase transitions thermodinamically, time-dependent for heat exchanged between the system and its environment can be investigated from its time-dependent temperature change, namely [9]

$$\Delta Q = mc\Delta T + m\Delta h(T) \tag{1}$$

or

$$\frac{\mathrm{d}}{\mathrm{d}t}\Delta Q = mc\frac{\mathrm{d}}{\mathrm{d}t}\Delta T + m\frac{\mathrm{d}}{\mathrm{d}t}\Delta h(T) \tag{2}$$

Figure 3 give the experimental results for water (a), CO (b), and salt hidrate $CaCl_2.6H_2O$ (c) as the system. The heat exchanged between the system and environment is indicated by the increase in system's temperature (red lines) from below 15ºC and reduction of water's temperature as the environment (black lines) from about 28ºC to a certain equilibrium temperature. The equilibrium temperature is indicated by the mutual coincident between the system's temperature and environment's temperature. The equilibrium temperature of water as the system is almost similar with CO, while $CaCl_2.6H_2O$ shows much lower value (table 1). Although this result is consistent with the picture of heat absorption capability as shown in figure 1, it also indicates that heat absorption of CO is not as optimal as the $CaCl_2.6H_2O$.

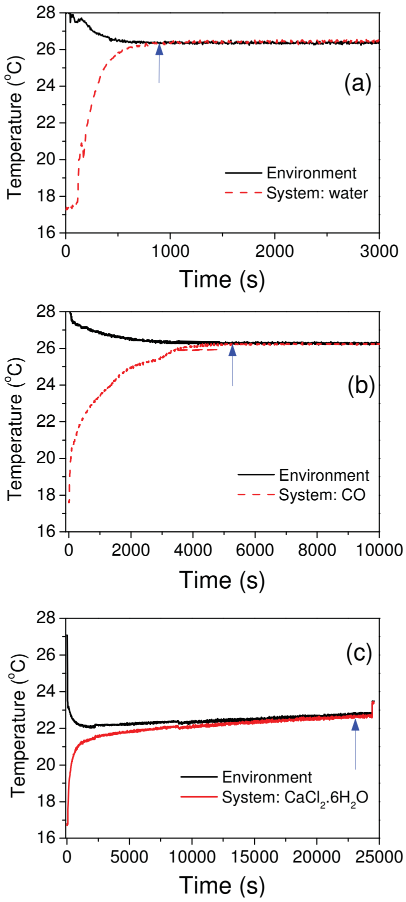

Figure 3. The experimental results for the heat exchanged between system and water environment. The systems consist of: (a) water, (b) PCM CO, and (c) PCM $CaCl_2.6H_2O$. The black lines indicate the heat release from the environment and the red lines indicate the heat absorption of the system. For each figure, the equilibrium temperature as indicated by the arrow is determined by the coincidence between the black and red lines.

Table 1. The equilibrium temperature of water, CO and $CaCl_2.6H_2O$ as the system, and the estimated amount of samples that takes place in the solid-liquid phase transition.

System	The equilibrium temperature (ºC)	Portion of sample in the solid-liquid phase transition (%)	Effectiveness (ºC/kg)
Water	26.4		0.8
CO	26.2	10	0.9
$CaCl_2.6H_2O$	22.7	60	2.7

Applying the energy conservation law (Black's rule) that the heat release from the environment is equal to the heat absorption by the system and the adiabatic container, one might calculate the estimated amount of each sample that plays the role in the solid-liquid phase transition, and the calculation results are shown in table 1. From this table, the relatively small amount of CO (~ 10%)

have to be compared with substantial amount of $CaCl_2.6H_2O$ (~60%), indicating that in this temperature range the CO is not so optimal in the heat absorption behavior compared with those of $CaCl_2.6H_2O$. We note that the previous study for the heat absorption performance of CO using Differential Scanning Calorimetry (DSC) has shown that its highest capability is limited in the temperature range of 22-33ºC, although its working range is in between 12 to 35ºC [10].

The effectiveness of CO and $CaCl_2.6H_2O$ as latent heat energy storage system can be measured by its maximum capability to decrease the air temperature for one unit volume of air environment; for this setup experiment it is measured as its maximum capability to decrease the water environment temperature for one unit amount of water, and in this case it can be taken as 1 kg or 1 litter of water. The bigger that value, the better performance of the system to be used as the thermal energy storage in water medium as the environment. The result for this analysis is shown at the right column of table 1. It clearly show that $CaCl_2.6H_2O$ has the highest value of effectiveness compared with those of CO or water, and it might be directly related with its high value of enthalpy that must be responsible for the solid-liquid phase transition.

4. Summary

We have shown in this paper that in the working temperature range of 15-28ºC and water as the medium of the environment, the CO and $CaCl_2.6H_2O$ have better performance compared with those of water as the of thermal energy storage for application of room temperature conditioning system. This is due to the fact that in this temperature range the heat absorption of CO and $CaCl_2.6H_2O$ involve the sensible and latent heats, while water only stores the sensible heat. The relatively small portion of CO that contribute in the heat absorption is due to the fact that the best capability of CO is limited in the temperature range of 22-33ºC, although its working range is in between 12 to 35ºC from previous DSC data.

Acknowledgements

This research is funded by Program Insentif Riset SINAS Indonesia under contract number: 558.a/I1.C10/KU/2015.

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