Experimental investigation of a cold storage box with Aceh locally produced hydrated salt as phase change materials: effect of salt treatment

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1. Introduction

Increasing levels of greenhouse gas emissions and fuel prices lead us to try more effectively use a variety of renewable energy sources, like solar radiation, wind energy, geothermal energy, etc. To build a new and renewable energy source, one thing that needs to be considered is to make energy storage devices. There are several energy storage methods such as: mechanical, electrical, thermochemical and thermal energy storage [1]. Thermal Energy Storage (TES) is one technology that essentially reduces total energy consumption and maintains original fossil fuels. In the storage of thermal energy can be divided into two parts, namely sensible heat storage, and storage of latent heat. Heat storage systems are a superior way of storing thermal energy. This is due to the high storage density and natural isothermal of the storage process. One of the thermal energy storage method is the use of Phase Change Material (PCM) [2].

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PCM is one of the energy storage materials that use the principle of latent heat, where energy is stored when a phase changes in a relatively constant temperature. This type of material will store heat energy when it changes phase from solid to liquid, or from liquid to gas, then this material will release heat energy when the phase changes otherwise [3].

In this study, we focused on PCM applications in cold storage. Currently, there are many cold storage requires continuous supply of electrical energy to keep the stability of food products stored in it. This consumes a lot of energy and costs. By using PCM materials, energy consumption can be reduced by applying the concept of a hybrid system to the cooler where electrical energy is only used to freeze PCM material. For cold applications, PCM material necessarily has freezing temperatures below 0°C. One of the most suitable materials is a solution of water and salt. Han et al [4] examined the preparation of eutectic binary solutions of sodium chloride and water. The study states that the solution can produce melting points reaching -22°C. Eutectic solutions of water and salt are generally used as PCM for cold storage, but in practice, this solution has a problem with the imperfection of the freezing process that occurs due to super cooling. The water and salt solution freezes with variations in composition and addition of nucleating agents. The results of the study gave a decrease of super cooling degree of 0.87°C on the addition of 1w% nucleation agent in NaCl/H2O [5]. Furthermore, a recent work by Gunawati et al. reported that the addition of 10% NaCl in water can increase the ability to release and absorb heat up to 73% compared to pure water[6].

This study aims to use other materials as PCM, which was produced locally salt taken directly from Lamujong, Aceh Besar District of Indonesia. This local salt is unique due to the process of salt production is still very traditional. There are four types of samples to be investigated which are PCM (i) consists of 100% water; (ii) consists of 10% untreated-NaCl + water; (iii) consists of 10% treated-salt at a temperature of 400°C + water; (iv) consists of 10% treated-salt at a temperature of 600°C + water. The objective of this study is to investigate the heat transfer rate and temperature changes occurred in a 5 liter-cooler-box.

2. Experimental methods
The heat treatment of salt was carried out by the following steps: (a) weight the sample; (b) place the sample into alumina dish then heated in the Muffle furnace at heating rate of 10 °C/min until 400°C and hold for 30 minutes; (c) cooled-down the sample to room temperature. A similar procedure was performed at temperature 600 °C. Figure 1 shows the images of treated-salt at 400 °C and 600 °C. Preparation of salt solution was performed by mixing 10 wt.% of treated-salt with water. The solution was stirred until the mixture is evenly distributed, then filled into PCM bottles followed by freezing in a freezer. PCM bottles were placed in a cooler box which consists of wood box, styrofoam and aluminium layers. Figure 2 displays the photograph of cooler box and PCM bottle.

![Figure 1. Aceh local salt treated at 400°C and 600°C.](image-url)
Performance test for PCM was carried out by the following steps:

a. Prior to PCM bottles is inserted into the cooler, the initial temperature of PCM is recorded ($T_3$), the initial temperature inside cooler box ($T_2$) and the initial temperature of the water contained in aluminium cup ($T_1$), and the ambient temperature ($T_4$).

b. Four PCM bottles was placed within the wall of cooler box, and then closed tightly to ensure no energy enters and exits the system (Adiabatic Process).

c. Ensure the measuring device is functioning properly and has been calibrated first.

d. Data retrieval is carried out every 5 minutes to 8 h using a thermometer and digital thermocouple. The position points of temperature measurement are shown in Figure 3. $T_1$ is temperature of water filled in aluminium cup as energy recipient. $T_2$ is temperature inside cooler box. $T_3$ is temperature of PCM and $T_4$ is environment temperature.

e. The process of number a to d was repeated on each sample.

3. Result and discussion

Figure 4 shows the temperature profiles observed during discharging process of 100% H$_2$O PCM. Initially, the temperature inside PCM bottle (100% Water) is -15.5°C, and reaches 0°C after 3 h (180 minutes) experiment. Furthermore, the final temperature of this type of PCM is at 6.3°C within an interval of 8 h measurement.
Figure 4. Temperature profiles versus time of PCM containing 100% H₂O. $T_1$ = ; $T_2$ = ; $T_3$ = ; $T_4$ = 

The temperature gradients of PCM containing 10 wt.% untreated-NaCl+H₂O recorded during discharging process are plotted in Figure 5. No significant changes have been detected on the temperature of styrofoam wall as well as room temperature. However, the temperature of receiving media (water in aluminum cup) decreases following increases in PCM temperature within first two hours. This means an exchange of energy is occurred. This phenomenon is observed from all samples tested in this study. Compared to 100% H₂O PCM, adding 10 wt.% non-treated salt in water benefits in lowering the temperature of PCM from -15.5 to -27°C. This suggests that the effectiveness of released and absorbed energy is significantly improved by mixing salt and water [6].

Figure 5. Temperature profiles versus time of PCM containing 10 wt.% untreated-NaCl+H₂O. $T_1$ = ; $T_2$ = ; $T_3$ = ; $T_4$ = ;
Figure 6. Temperature profiles versus time of PCM containing 10 wt.% of NaCl treated at 400 °C. \( T_1 = \ldots; T_2 = \ldots; T_3 = \ldots; T_4 = \ldots \)

Performance test results on PCM solution of 10 wt.% NaCl treated at 400 and 600°C are plotted in Figures 6 and 7. Initial temperature detected from PCM of 400°C treated salt is lower compared to 600°C treated-salt. It is noteworthy that during charging process, 600°C treated salt takes nearly three days to turn into solid phase while non-treated and 400°C treated salts is frozen within 24 h.

Figure 7. Temperature profiles versus time of PCM containing 10 wt.% of NaCl treated at 600°C. \( T_1 = \ldots; T_2 = \ldots; T_3 = \ldots; T_4 = \ldots \)
Figure 8. Combined graph of temperature changes of water in aluminum cup (T₁). ◇ = PCM 100% H₂O; □ = PCM 10 wt% non-treated NaCl + H₂O; △ = PCM 10 wt% NaCl treated at 400°C; × = PCM 10 wt% NaCl treated at 600°C.

Combine graph of T₁ and T₃ from all tests are plotted in Figures 8 and 9. This combination helps in finding the effect of salt pre-treatment procedure. In term of temperature of water in the cup (T₁), no significant difference is observed. Meanwhile, the temperature gradient of each type of PCM’s exhibit differently. The best PCM solution is 10 wt.% 400°C treated salt diluted in water. Heat-up the salt up to 600°C does not give positive effects on the performance of cooler box enveloped with PCM. Indeed, stored-energy capacity is enhanced by mixing 10 wt.% untreated salt into water.

Figure 9. Combined graph of temperature changes in PCM bottles (T₃). ◇ = PCM 100% H₂O; □ = PCM 10 wt% non-treated NaCl + H₂O; △ = PCM 10 wt% NaCl treated at 400°C; × = PCM 10 wt% NaCl treated at 600°C.

4. Conclusions
Investigation on the temperature changes during energy discharging process of water-salt solution PCM has been done in a 5 litter special purpose cooler-box. Changes in temperature recorded during experiment suggest a positive effect on thermal energy storage capacity. Salt treated by heating to a temperature of 400°C displays the best performance, compared to the heating treatment to a temperature of 600°C.
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