Development and Characterization of Jatropha Oil as Innovative Bio-sourced Phase Change Material for Thermal Energy Storage

Made Rasta[1a], Nyoman Suamir[1b], Wayan Adi Subagia[1c], Adi Winarta[1], Ketut Bangse[1d] and Gusti Ketut Puja[2e]

[1]*Mechanical Engineering Department, Bali State Polytechnic, Bali-80364, Indonesia*

[2]*Mechanical Engineering Department, Sanata Dharma University, Yogyakarta-55002, Indonesia*

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Abstract: Thermal energy storage (TES) using phase change materials (PCM) is very promising to meet future energy needs because of its high storage capacity and low cost. This study aims to develop Jatropha oil as a new candidate for solid-liquid latent heat energy storage for cold storage applications. The characteristics of Jatropha oil as a candidate for PCM were tested experimentally using T-history methods. The test results show that Jatropha oil as a PCM candidate does not undergo super-cooling or super-cooling is very small compared to tap water and mineral water of 10 K and 15 K. The phase transition temperature of Jatropha oil ranges from -14 ºC to -16 ºC, lower than with tap freezing point and mineral water at 0 ºC. Thus, the candidate PCM has good thermal properties that can meet the thermal energy storage requirements for cold storage applications.

1 INTRODUCTION

Along with the increase in the economy and population development, the need for energy is increasing. Energy is a vital need in development. Energy is still sourced from fossil fuels which can cause climate change and environmental degradation. Therefore, it is important to save energy and use new and renewable energy sources that are environmentally friendly for sustainable development. Energy storage (ES) systems play an important role in supporting energy security. Energy can be stored in electrical, mechanical and thermal energy.

One of the important ES systems for storing and retrieving energy for energy conversion systems is thermal energy storage (TES). The use of a TES system based on latent heat technology can save energy use from fossil fuels and conserve energy. TES helps rational use of thermal energy and has the advantage that it allows the transfer of peak loads beyond peak loads, is significant in energy savings and mitigation of CO_2 that causes pollution to the environment.

Latent heat thermal energy storage (LHTES) is an attractive technique because it can provide a higher energy storage density than conventional TES systems. Has the ability to store the heat of fusion at a constant (relatively constant) temperature corresponding to the phase transition temperature of the phase change material (PCM).

One of the typical applications of PCM is for the storage of solar thermal energy which is considered the most abundant renewable energy. Utilization of PCM for TES can overcome the intermittency of solar energy, thus providing a better solution to rationalize the utilization of solar thermal energy, compared to the sensible heat TES system.

ES is a promising power management method to obtain sustainable energy utilization. ES using

[a] https://orcid.org/0000-0002-9610-3738
[b] https://orcid.org/0000-0003-0594-7511
[c] https://orcid.org/0000-0001-9261-3549
[d] https://orcid.org/0000-0003-0220-056X
[e] https://orcid.org/0000-0002-6025-3865

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LHTES is currently receiving a lot of attention to reduce grid energy requirements.

TES schemes using PCM are categorized into organic, inorganic and organic-inorganic mixtures. Organic PCMs, such as paraffin and fatty acids, have little super-cooling properties (no super-cooling occurs) because they have self-nucleation but lower thermal conductivity and higher cost. Inorganic PCMs, such as hydrated salts, are readily available and less expensive, but occurs phase separation, and corrosive (Rasta and Suamir, 2019). Therefore, it is important to select the optimal PCM in a given application to meet operating and cost requirements.

The main problem of TES technology is developing effective PCM for energy storage (Wang & Lu, 2013). The main criteria in determining the selection of PCM material types for TES applications are to have a phase change temperature in the practical application range, have high latent heat and good thermal conductivity, as they involve the energy storage and thermal stability characteristics of the PCM.

By far the most famous PCM is water because it has good thermal properties, but has the disadvantage of high super-cooling (Rasta and Suamir, 2018). In this study, Jatropha oil was developed as a PCM material. Oil is a complex fatty acid/fatty acid ester. Oils or fatty acids are a new class of organic PCM materials and the thermal data available in the literature are still limited (Aydin & Okutan, 2011). Oils or fatty acids are derivatives of materials easily found in nature and are labelled as bio-based ingredients (Cellata, et al., 2015; Sharma, et al., 2015). Another advantage is that vegetable oils are available continuously (Sharma, et al., 2014; Fauzi, et al., 2015; Suamir, et al., 2019).

Given the complexities of LHTES problems, developing an effective PCM for energy storage in a suitable form is still a big challenge and many methods have been sought (Yingbo, et al., 2014). The aim of this paper is to develop new bio-materials for low temperature thermal energy storage below 0 ºC for refrigeration system applications.

2 MATERIAL AND METHOD

The material used as Latent Heat Thermal Energy Storage in this research is Jatropha oil. Jatropha oil was chosen because of its sufficient availability in the field and cultivated by farmers to increase their income. The Jatropha oil tested here has undergone a hydrolysis process. Jatropha oil contains various fatty acids, both saturated and unsaturated fatty acids (PUFA).

The thermal properties of Jatropha oil will be compared with the thermal properties of tap water and mineral water. Water is an excellent PCM material, but has the disadvantage of high super-cooling and a freezing point of 0 ºC. The results of the Jatropha oil test will be compared with water, to explain the characteristics of Jatropha oil.

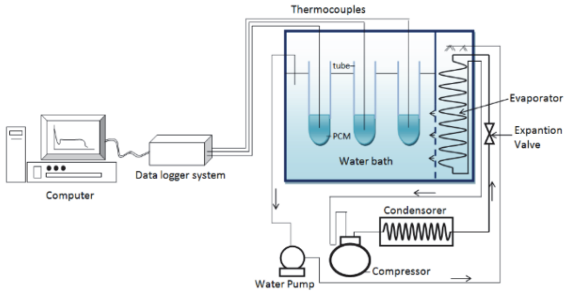

Figure 1: Schematic diagram of the experimental test equipment T-history method (Rasta, et al., 2016a).

Figure 1 shows that the prospective PCM Jatropha oil in various volumes is put into a glass tube and immersed in a water bath as a cooling medium. The cooling medium is a mixture of 40% (volume) polypropylene glycol with tap water. The cooling medium is circulated by pump through the evaporator of the system. The temperature of the cooling medium can be as low as -25 ºC. However, for testing, the temperature of the cooling medium was maintained stable at -20 ºC by using a digital thermostat with an accuracy of ±0.2 ºC.

The data recording system shown in Figure 1 is equipped with a data acquisition module and a computer for recording or display systems. The data acquisition module utilizes the Data scan 7000 series from MSL (Measuring Systems Ltd) which includes the Data scan 7320 measurement processor and the 7020 expansion module. Type T thermocouples are used to measure the temperature of the PCM candidate and cooling medium. The thermocouple has a temperature measurement range of -250 ºC to 350 ºC with an error of ± 0.5 ºC. The thermocouple was calibrated using a water bath calibration and the uncertainty of the thermometer precision was ± 0.04 ºC. In the test temperature range is -25 ºC to 50 ºC (Rasta, et al., 2016b).

3 RESULT AND DISCUSSION

Super-cooling degree is an important parameter in LHTES technology using PCM. Figures 2 and 3 show that tap water and mineral water have high super-cooling, namely 10 K and 15 K. Super-cooling is a condition that indicates the presence of tap water and mineral water still in liquid form below the freezing point of 0 ºC. A LHTES technology with high super-cooling, will result in a much lower evaporation temperature required when applied in the cooling system. Thus will reduce the performance of the system. In addition, before tap water and mineral water freeze, the energy stored is only in the form of sensible heat, causing a very small energy storage capacity. In order for tap water and minerals to store energy in the form of latent heat, more energy is needed to change the state from liquid to solid. The greater energy requirements in PCM technology are in direct conflict with thermal energy storage technology. So high super-cooling is a disadvantage in LHTES technology

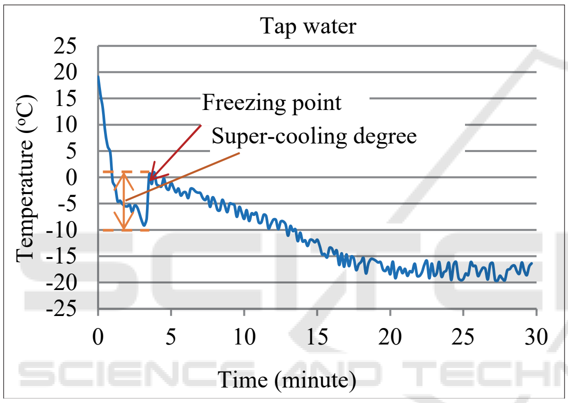

Figure 2: Cooling process and super-cooling tap water.

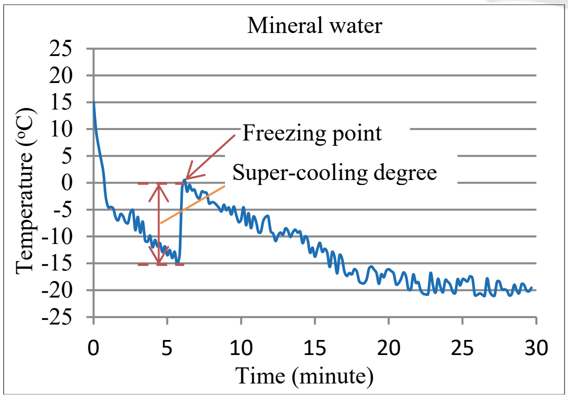

Figure 3: Cooling process and super-cooling mineral water.

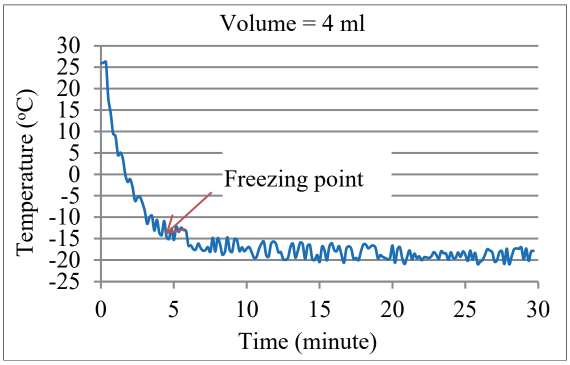

Figure 4: Cooling process and Jatropha oil freezing point for sample 4 ml.

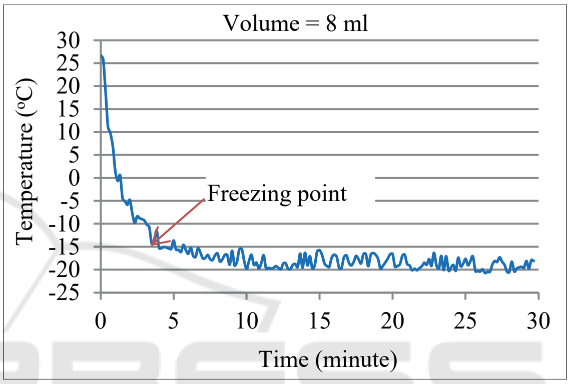

Figure 5: Cooling process and Jatropha oil freezing point for sample 8 ml.

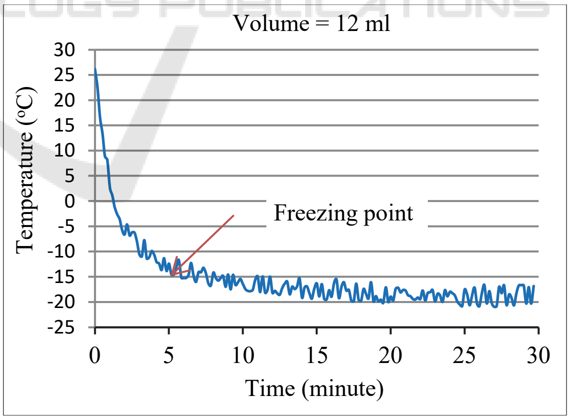

Figure 6: Cooling process and Jatropha oil freezing point for sample 12 ml.

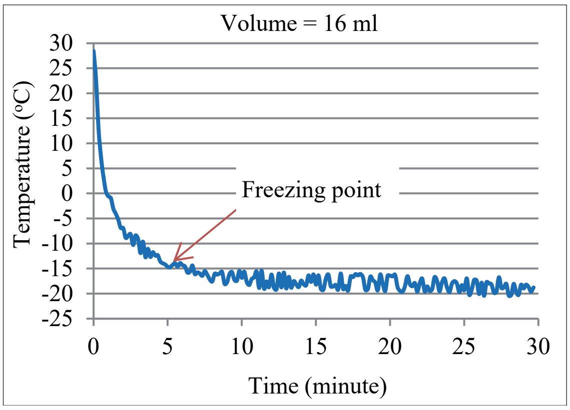

Figure 7: Cooling process and Jatropha oil freezing point for sample 16 ml.

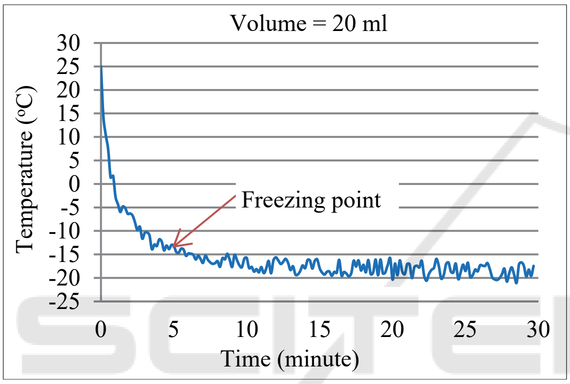

Figure 8: Cooling process and Jatropha oil freezing point for sample 20 ml.

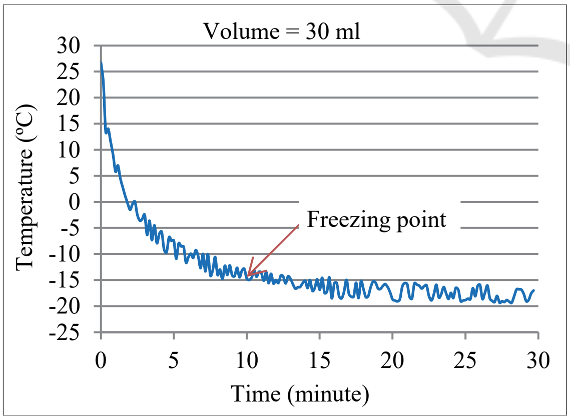

Figure 9: Cooling process and Jatropha oil freezing point for sample 30 ml.

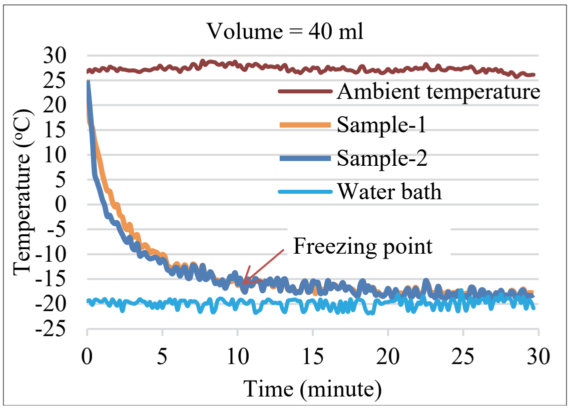

Figure 10: Cooling process and Jatropha oil freezing point for sample 40 ml.

Table 1: Thermal energy storages properties of tap water, mineral water and Jatropha oil.

Samples (Volume, ml)	Cooling process	
	Freezing temperature (ºC)	Super-cooling degree (K)
Tap water, 20 ml	0	10
Mineral water, 20 ml	0	15
Jatropha oil, 4 ml	14	0
Jatropha oil, 8 ml	14	0
Jatropha oil, 12 ml	15	0
Jatropha oil, 16 ml	15	0
Jatropha oil, 20 ml	15	0
Jatropha oil, 30 ml	16	0
Jatropha oil, 40 ml	16	0

Figures 4-10 shows the cooling process of each volume variation of the Jatropha oil sample developed as PCM. The test results of the T-history method show that in the early stages of the cooling process, there is a very rapid decrease in temperature to the initial limit of the transition phase temperature process. At the beginning of the phase transition process until it ends there is no significant or constant temperature change. When a phase transition occurs from the beginning to the end, this is where the storage of latent heat energy occurs. After that the freezing process takes place, the temperature decreases towards the final test temperature setting.

Overall, all samples developed with different volume fractions of Jatropha oil are summarized in Table 1. The freezing point of the PCM candidate developed is lower than that of tap water and mineral water. The freezing point of Jatropha oil in various volumes of 4 ml, 8 ml, 12 ml, 16 ml, 20 ml, 30 ml and 40 ml, ranged from -14 ºC to -16 ºC. The results showed that increasing the volume of the sample tested did not significantly affect the change in freezing point. Thus, the advantages of Jatropha oil do not occur super-cooling, have stable properties, are not corrosive and environmentally friendly. These properties make Jatropha oil a potential PCM material for energy storage for latent heat thermal energy storage applications in low temperature refrigeration systems below 0 ºC, compared to water (tap water and mineral water).

4 CONCLUSIONS

An investigation of Jatropha oil as a candidate for the development of a new phase change material (PCM) has been carried out. T-history thermal analysis was applied in the investigation and it was found that Jatropha oil has a phase transition temperature or freezing point ranging from -14 ºC to -16 ºC. The results of the investigation also found that the candidate PCM under test conditions had a minimum or even none (negligible) super-cooling level. In addition, Jatropha oil has a continuous supply, is non-corrosive and non-toxic. Meanwhile, tap water and mineral water have high super-cooling, which are 10 K and 15 K, respectively, with a freezing point or phase transition temperature of 0 ºC. This makes Jatropha oil applicable as a new PCM for cold storage applications below 0 ºC.

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