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Thermal characteristics of non-edible oils as phase change materials candidate to application of air conditioning chilled water system

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Abstract. The addition of phase change material in the secondary refrigerant has been able to reduce the energy consumption of air conditioning systems in chilled water system. This material has a high thermal density because its energy is stored as latent heat. Based on material melting and freezing point, there are several non-edible oils that can be studied as a phase change material candidate for the application of chilled water systems. Forests and plantations in Indonesia have great potential to produce non-edible oil derived from the seeds of the plant, such as; *Calophyllum inophyllum*, *Jatropha curcas* L, and *Hevea braziliensis*. Based on the melting temperature, these oils can further studied to be used as material mixing in the secondary refrigerant. Thermal characteristics are obtained from the testing of T-history, Differential Scanning Calorimetric (DSC) and thermal conductivity materials. Test results showed an increase in the value of the latent heat when mixed with water with the addition of surfactant. Thermal characteristics of each material of the test results are shown completely in discussion section of this article.

1. Introduction

One of energy crisis' solutions is its efficient consumptions. It is stated that the largest percentage spent for electric consumption on commercial blocks is in their air conditioning systems as demonstrated in United States and China which spend 38 percent [1], Malaysia 57 percent [2], and Indonesia spends more than 65 percent [3]. Methods are being developed to reduce electrical energy consumption in the air conditioning system and one of them is the use of phase change materials (PCM) as thermal energy storage (TES) [4].

Freezing and melting temperature between 5-12°C [5] are important considerations when selecting PCM in order to adjust them to the evaporator of chiller's temperature. Fatty acid's melting temperature ranges from -5.6 up to 79 °C with latent heat ranging from 126 to 212kJ/kg [6]. Experimented organic PCM from fatty acid like biodiesels from crude palm oil (CPO) [7] and soybean oil [8] are potential candidates material to be mixed into secondary refrigerant. Since these biodiesels are also utilized as edible oils, their functions as PCM should be reconsidered for further development.

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On the other hand, many types of non-edible oil PCM from oilseeds of forest trees and plantation plants are promising candidates to be developed as mixing material. Among the seeds, there are *Calophyllum inophyllum*, *Jatropha curcas* L, and *Hevea brasiliensis*. Those tropical plants are widely spread in many countries. The oil content in those three diverse plants is relatively high as it is displayed in Table 1.

Table 1. Non edible oils potential

	Seed production tonnes/(ha.year)	oil content in seeds (%)	kg oil/ (ha.year)	Density (kg/m ³)	Viscosity (cSt)
<i>Calophyllum inophyllum</i>	16 ^[9]	40 - 73 ^[10]	4680 ^[10]	896 ^[11]	71.98 ^[11]
<i>Jatropha curcas</i>	0.1 - 15 ^[10]	37 - 45 ^[12]	1900 - 2500 ^[10]	920 ^[11]	18.2 ^[11]
<i>Hevea brasiliensis</i>	0.15 ^[13]	40 - 50 ^[11]	40 - 50 ^[11]	910 ^[11]	66.2 ^[11]

Vegetable oil is composed of diverse fatty acids, both saturated and unsaturated fats. The most fatty acid composition is palmitic and stearic from saturated group; oleic, linoleic, and linolenic from unsaturated ones. Fatty acids percentage from seeds of *Calophyllum inophyllum*, *Jatropha curcas* L, and *Hevea brasiliensis* are shown on Table 2.

Table 2. The content of fatty acids from nonedible oil

Fatty acid	Name Structure	Fatty acid composition (%)				Melting point (°C) ^[c]	Latent heat (kJ/kg) ^[d]	Types of fatty acids
		CISO ^[a]	JCSO ^[a]	CPO ^[b]	HBSO ^[a]			
Palmitic	Hexadecanoic (C16:0)	12.01	16.00	43.50	10,20	60,45	221.42	saturated fatty acid
Stearic	Octadecanoic (C18:0)	12,95	6.50	4.30	8,70	66,87	242.15	saturated fatty acid
Oleic	cis-9-Octadecenoic (C18:1)	34.09	43.50	39.80	24,60	13 s/d 14	138.07	monounsaturated fatty acid
Linoleic	cis-9,cis-12-Octadecadienoic (C18:2)	38.26	34.40	10.20	39,60	-9 s/d -8	n/a	polyunsaturated fatty acid
Linolenic	cis-9,cis-12,cis-15-Octadecatrienoic (C18:3)	0,30	0.80	0,30	16,30	-17	n/a	polyunsaturated fatty acid

^a [13], ^b [14], ^c [15], ^d [16]

Based on the potency and composition of fatty acids within the plant *Calophyllum inophyllum*, *Jatropha curcas* L, and *Hevea brasiliensis*, these oilseeds can be further researched as candidates of phase change materials for air conditioning system. It still is necessary to test the thermal characteristics such as freezing and melting temperature, latent heat and the concentration of solids.

2. Experimental

Thermal characteristics had been obtained using the T-history test and differential scanning calorimetry (DSC). The T-history testing was done on cooling rate ranged from 0.10 to 0.25°C/min with a sample mass of 70 g. DSC test used a Perkin Elmer type 8500. Criteria referenced in this DSC testing were as follows; mass of the sample is 5 - 7 mg, cooling and heating rate was 2°C/min, and the sample was cooled from 25 to -30°C and heated from -30 to 35°C. The nitrogen flow rate of cooling was 20 ml/min. Testing of the solid mass concentration was done by taking samples at temperatures of

6 to 10 °C during cooling and heating. Mass of solids was separated from the liquid and then a solid mass was measured.

3. Result and Discussion

The result of T-history testings for three vegetable oils indicated several findings. First, their freezing temperatures were able to achieve evaporator' performing condition as displayed on Table 3. Second, different treatment for *Jatropha curcas* seed oils (JCSO) was executed. It needed *Crude palm oil* (CPO) added in such composition of 93% : 7%. Third, the highest fatty acid composition percentage on *Calophyllum inophyllum* seed oil (CISO) is oleic; 48.49% and linoleic 20.70% with melting temperatures 13 – 14°C and -9 to -8°C respectively. These two fatty acids contributed to freezing temperature value of CISO. Similar compositions were signified in JCSO and *Hevea brasiliensis* seed oil (HBSO), in which oleic and linoleic had the highest percentages. Having different treatment using CPO, JCSO is composed mainly of 46.9% palmitic in melting temperature 6045°C. Consequently, CPO's melting temperature is crucially high; 20.13°C and 46.36°C [17]. The melting temperatures on fatty acids were governed by hydrocarbon chains. These linear hydrocarbon chains were in saturated fatty acids like palmitic and stearic. On the other hand, one or more chains with double carbon ties were in unsaturated fatty acid like oleic and linoleic. Unsaturated fatty acid was formed by monounsaturated fatty acid and polyunsaturated fatty acid. Another controlling factor is that melting temperature is parallel with the chain length in saturated fatty acid, while is opposite to unsaturated level [18]. Melting temperature of saturated fatty acid is higher than unsaturated one because saturated fatty acid has stabile thermodynamic feature [19].

Table 3. Freezing temperature of nonedible oil with T-history test

Phase change material	Composition (%)	Freezing temperature (°C)
CISO	100	12.77 – 5.26
JCSO + CPO	93 + 7	12.02 – 2.44
HBSO	100	11.57 – 1.73

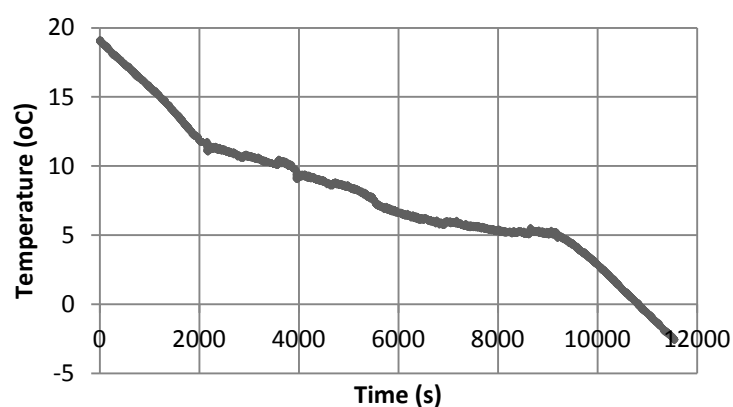


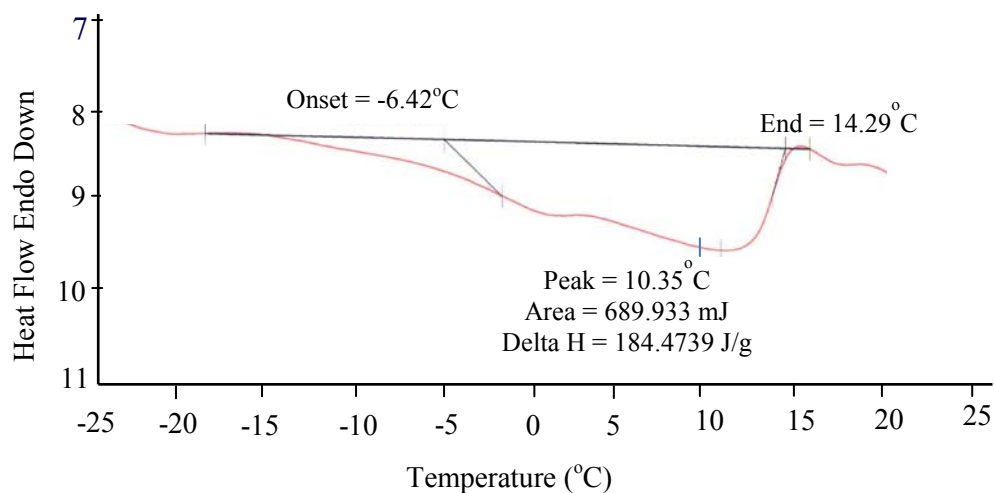
Figure 1. T-history test of CISO for cooling process

DSC test results of nonedible oil are shown in Table 4. Temperature and HBSO CISO crystallization from DSC test is not quite distinctive from the T-test history. This difference was caused by different cooling rates between the two tests. HBSO melting temperature was almost equal to the melting temperature of Malaysian rubber seed oils (MRSO) which were tested by Abdullah et al, but HBSO freezing temperature is much higher than MRSO [20]. This difference could be caused by the content of fatty acid composition.

Table 4. Melting and freezing characteristic of nonedible oil with DSC test

PCM	Freezing				Melting			
	T _{onset} (°C)	T _{peak} (°C)	T _{endset} (°C)	Latent heat (kJ/kg)	T _{onset} (°C)	T _{peak} (°C)	T _{endset} (°C)	Latent heat (kJ/kg)
CISO	11.85	9.41	4.12	32.8039	-6.42	10.35	14.29	184.4739
JCSO + CPO	-14.81	-14.98	-15.59	21.1714	-11.19	-1.79	3.57	8.4387
HBSO	6.26	5.84	5.37	0.3872	-11.41	-4.52	-0.82	9.3000
CISO + water	-11.57	-11.66	-12.26	188.3105	11.08	15.23	16.12	219.7453
JCSO + CPO + water	-11.09	-11.20	-11.69	78.2715	10.48	12.70	13.54	95.0304
HBSO + water	-8.45	-8.53	-9.02	153.2356	9.80	12.69	13.44	171.4922

The freezing and melting process of the nonedible oils had occurred on a large temperature range. Figure 2 shows the melting process for the CISO, where it started at a temperature of -6.42°C and finished at a temperature of 14.29°C. These results were consistent with the research results of Indartono et al to coconut oil and JCSO with the ratio of 1: 1 [8]. DSC test results for a solution of oil in water by adding anionic Texapon surfactant as much as 500ppm showed latent heat higher than the seed oil. Temperature range for freezing and melting processes are very small. Figure 3 shows the melting process for solution of CISO in water, where it started at a temperature of 11.08°C and finished at a temperature of 16.12°C. The addition of seed oils affected the temperature of crystallization and melting of water in the mixture. This finding was consistent with the results of the research of Tippets and Martini, where increasing oil concentration of 20% to 40% could increase the melting temperature [21].

**Figure 2.** DSC curve of CISO in heating process

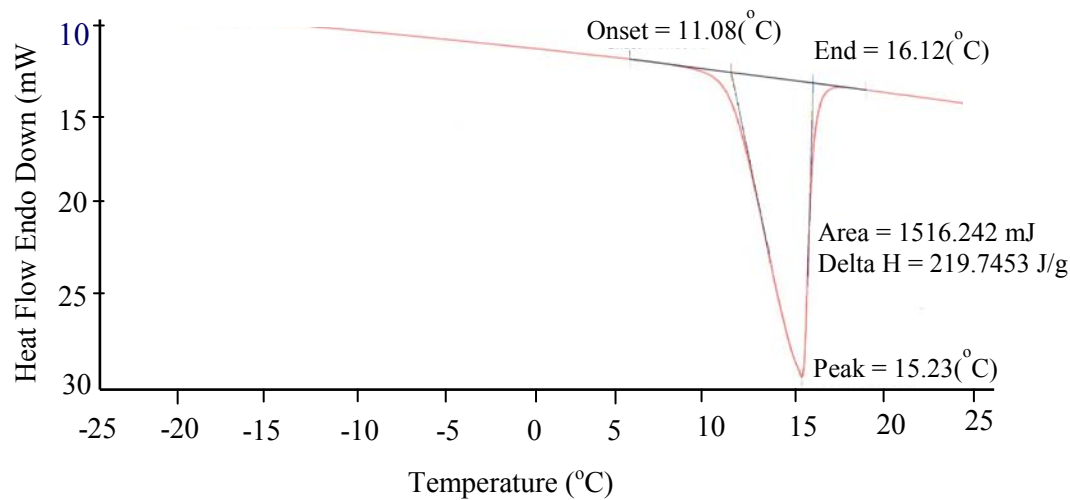


Figure 3. DSC curve of CISO slurry in heating process

Solid mass concentrations for PCM slurry in the heating and cooling process is shown in Figure 4. In the heating process, the concentration of solid mass was reduced from 24.359% at temperatures 7°C, to 22.60% at temperatures 9°C. While in the process of cooling, solid mass concentration increased from 33.13% at the temperature 9°C, to 37.22% at temperatures 7°C. These changes were caused by the melting and freezing processes. Energy from the utilized latent heat was proportional to change in the solid mass concentration of PCM slurry.

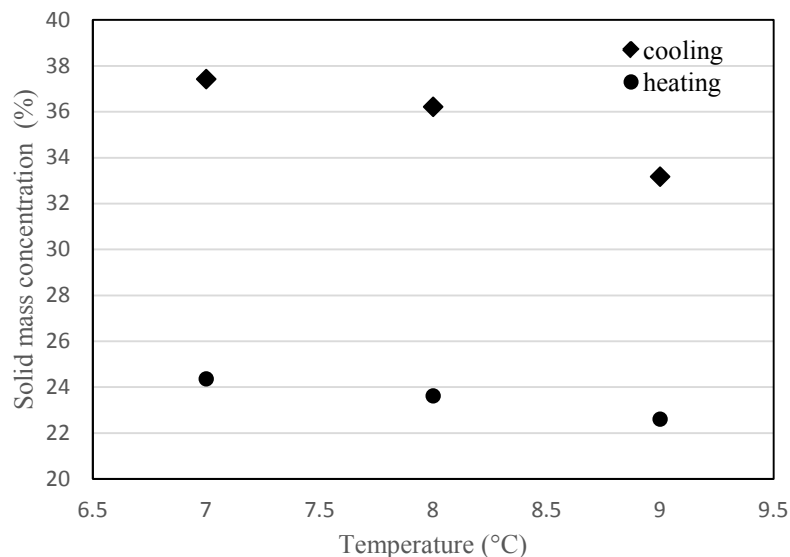


Figure 4. Solid mass concentration of CISO slurry

Referring to the results of observations on the mass concentration of the solid test and t-test of history, in which the process of freezing and melting of non-edible oil for the third is still in accordance with the evaporator temperature, they can be used as candidates of material mixing in secondary refrigerant. CISO and HBSO were more potential to be developed because after they were dissolved in the water, latent heat was high. CISO slurry had a latent heat of 219.745kJ/kg and HBSO slurry had 171.4922kJ/kg.

4. Conclusion

Several conclusions could be drawn from the experiments. Firstly, CISO and HBSO had the prospect to be developed into mixing material in the secondary refrigerant as they were highly potential in availability. Secondly, melting and freezing temperatures were matched with evaporator temperature. Latent heat of two seed oils increased after they were mixed into the water. CISO latent heat of slurry on the melting process was 219.75kJ/kg and the freezing process was 188.31kJ/kg. Besides, the latent heat of HBSO slurry on the melting process was 171.49kJ/kg and the freezing process was 153.24kJ/kg. These mean that both seed oils are good thermal energy storage. Thirdly, utilized latent heat value is proportional to the change in solid mass concentration on the freezing and melting process. Since these materials were insoluble in water, it was necessary to conduct research to get surfactant that less affect the thermal properties of the materials.

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