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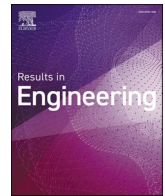- 2% Publications database
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Experimental study of the thermal properties of waste cooking oil applied as thermal energy storage

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ABSTRACT

Waste cooking oil is a residue containing 40%–60% cooking oil that has been used several times. It has a great potential that has not been widely explored considering the fact that residual oil is usually wasted in the drainage and soil with subsequent negative effects on the ecosystem. Cooking oils have potential to application in cooling rooms and this is the reason it is necessary to determine its thermal properties. Several tests were conducted in this study on the waste cooking oil and these include PCM compound composition determination using Agilent brand of Gas Chromatography (GC) type 7890 b, T-History, Differential Scanning Calorimetry (DSC) using DSC type 214 Polyma Brand NETZCSH, and thermal conductivity through the TCi Thermal Conductivity Analyzer Brand C-Therm. Some changes were observed in the type and composition of fatty acid compounds of cooking oil during the frying process such as the increase in the methyl arachidate from 10.71% to 45.68% in waste coconut cooking oil (WCCO). The WCCO is also very interesting to be developed as thermal energy storages considering the similarities it has with CCO such as the 97.7 kJ/kg latent heat for melting and 0.155 W/m.K thermal conductivity.

1. Introduction

Waste cooking oil (WCO) is the cooking oil that has been used several times to fry and is considered unsuitable for further use due to its negative impacts on human health. It also has the potential to present damage to the soil, water, and channels when discharged into the environment [1]. This was indicated by the findings of Fujita et al., 2015 that 51% of households dumped WCO into the drainage, 17% on the soil, 15% to their helpers, and 11% to the city recycling program [2]. The residual oil causes crust around the inner surface of pipes, thereby, leading to a reduction of the cross-sectional area of the channel, a decrease in the flow of wastewater, and an acceleration of the occurrence of blockages. Moreover, it reduces water quality which further leads to the death of aquatic ecosystems such as fish as well as other animals and plants. WCO causes soil compaction, reduces soil absorption rate, kills worms and microbes needed in soil fertility, and slows down germination. The oil also affects the morphology and toxic content of plants.

The potential for WCO is very large as indicated by the data from the Central Statistics Agency 2021 which showed that the average cooking oil consumed per capita per year is 11.58 L/capita/year which is a 12.1% increment compared to the 10.33 L/capita/year recorded in 2015. From several countries with the largest consumption of cooking oil, such as: China, Malaysia, the United States, Europe, Taiwan, Canada, Japan, and others, they have produced WCO of 16.54 million tons (Mt) each year, with two main sources namely: commercial WCO from hotels, restaurants and catering, and domestic WCO from households [3]. It is important to note that used cooking oil can produce 40%–60% WCO with only 18.5% retrievable. Efforts to utilize used cooking oils have been carried out by many researcher, such as: processed into soap [4], softening aged bitumen [5], and processed into biodiesel [6–9]. Some research conducted on cooking oil has yielded results, that cooking oil, especially from coconut oil, has the potential to be used as a storage of thermal energy for room cooling. Based on this, WCO also has the potential to store thermal energy for use in room cooling, but there is very little research on this, such as extracting the lauric acid contained in WCO and used as a thermal energy storage [10].

Several studies have been conducted using cooking oil as a Phase Change Material (PCM) with a focus on the physical and thermal properties as well as the fatty acid content [11–14], heat transfer characteristics of the freezing process [15], heat transfer characteristics of the melting process [16], and wall applications for room cooling [17].

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It was discovered that each PCM has a different melting point and latent heat energy and this means their use as thermal energy storage (TES) should be adapted to the application [18]. Meanwhile, the determination of the feasibility of using waste cooking oil as thermal energy storage requires studying its thermal properties and this is the focus of this study.

2. Methods

This study focuses on the thermal properties and content of WCO from coconut and palm oil after being used to fry. The process involved four tests which include the fatty acid composition using Gas Chromatography (GC), freezing and melting through the T-History method, Differential Scanning Calorimetry (DSC), and thermal conductivity tests.

2.1. Gas Chromatography method

The PCM samples from cooking oil and waste cooking oil were tested using the Gas Chromatography (GC) method to determine the amount and type of compounds contained. The test were used to analyze the amount of compound quantitatively through GC type 7890 b brand Agilent while mass spectrometry was applied to determine the molecular structure such as the number of carbon chain bonds. GC testing to obtain saturated and unsaturated fatty acids has been carried out through hydrolysis and methylation processes. In the hydrolysis process, the sample used was 5–10 g while in the methylation process the sample used was 0.5 ml. The results of the methylation process was injected as much as 1 μl into GC, at a temperature of 260C, and a pressure of 47.914 Psi.

2.2. T-history method

The freezing and melting processes in the PCM samples were determined visually using the T-History method. This involved recording the initial and final temperature and visually observing the changes in the freezing and melting of the PCMs. The tools used for this test include a refrigerator, thermocouple, temperature Recorder 12 Channel Lutron BTM - 4208SD, fan, and heater. The refrigerator was used for the freezing test while the fan and heater were applied for the melting process. The volume of the sample tested was 250 ml.

2.3. Differential scanning calorimetry (DSC) method

The latent heat value and the phase change temperature were determined using the differential scanning calorimetry (DSC) test through the application of the DSC type 214 Polyma Brand NETZCSH. The sample mass for DSC testing was 10.2 mg. The temperature range for testing the cooling process was 30 °C–0 °C and the heating process was 0 °C–30 °C. The cooling and heating rates were 5 K/min. The cooling process has used nitrogen.

2.4. Thermal conductivity

The thermal conductivity value of the samples were obtained using the TCi Thermal Conductivity Analyzer Brand C-Therm and each sample was tested 10 times in liquid form. The temperature difference is set at 1.5 °C and has used an electric voltage of 4.9 mV.

3. Results and discussion

This experimental study was conducted to obtain the thermal properties of cooking oil (CO) and waste cooking oil (WCO) and this is considered important for their utilization as thermal energy storage in cooling a room. The cooking oils used in this study were coconut and palm oil and the data obtained through the experimental test include the phase change temperature, sensible heat, latent heat, and thermal conductivity. It is important to note that the PCM compound composition was also determined using the Gas Chromatography (GC) method.

3.1. Fatty acid composition of cooking oil and waste cooking oil

The fatty acid content in the coconut, palm, and waste cooking oil is discussed in this section. The content for the coconut cooking oil (CCO) was obtained using the Gas Chromatography test and the results presented in Fig. 1 showed that nine peaks were detected with a retention time of 7.597, 9.788, 13.184, 17.750, 23.257, 27.489, 31.357, 35.532, and 36.434, respectively. Moreover, the nine main fatty acid compounds contained are summarized in Table 1 and the highest content was found to be 45.46% in M Tridecanoate followed by M Penthadecanoate with 17.85%, M Arachidate with 10.71%, and M Heptadecanoate with 10.34%, and they all have a combined fatty acid content of 84.36% in CCO.

The results for Waste Coconut Cooking Oil (WCCO) presented in Fig. 2 and Table 2 showed the detection of nine graph peaks with a retention time of 7.727, 13.042, 22.329, 26.825, 31.099, 35.392, 36.313, 37.510, and 39.748 respectively as indicated in Fig. 2. It was also discovered from Table 2 that the main fatty acid compounds in WCCO were M Arachidate, M Heptadecanoate, and M Linolenate with 45.68%, 36.09%, and 12.58%, respectively, and a combined total of 94.35%.

The comparison of CCO and WCCO showed a change in the percentage of compound content with some new fatty acid compounds discovered while some were lost as indicated in Table 3. The use of CCO to fry several times led to the extinction of the two largest fatty acid compounds including M Tridecanoate and M Penthadecanoate and the same trend was also observed for those with low percentages such as M Decanoate and M Hexanoate. Meanwhile, the content of M Arachidate, M Heptadecanoate, M Linolenate, and M Butyrate increased with Methyl arachidate observed to have increased significantly from 10.71% to 45.68% and became the most abundant fatty acid in WCCO. Methyl heptadecanoate also increased from 10.34% to 36.09% and became the second most abundant. It was also discovered that four new fatty acid compounds appeared even though their percentages were very small including M Laurate, Myristolleic AME, cis-11,14-Eicosadienoic AME, and M Tricosanoate.

The fatty acid composition of Palm Cooking Oil (PCO) was also determined using the GC test and the results presented in Fig. 3 showed that seven peaks were detected with a retention time of 7.719, 22.407, 26.945, 31.292, 35.607, 36.461, and 37.615 respectively with each peak indicating the type of fatty acid contained. These types are further presented in the chromatography chart of Table 4 with the most dominant found to include gamma-Linolenic AM, M Heptadecanoate, and M Linolenate at 46.04%, 35.63%, and 12.74%, respectively (see Table 5).

The GC test results of the Waste Palm Cooking Oil (WPCO) in the chromatography chart shown in Fig. 4 indicated that the retention time for each peak was 7.641, 9.797, 13.203, 17.776, 23.323, 27.566, 31.381, 35.460, and 36.396. The repeated frying process was observed to have changed the type and percentage of fatty acids as indicated in Table 4. The dominant types were recorded to be M Tridecanoate, M Penthadecanoate, cis-10-Heptadecenoic AME, and M Arachidate with 48.41%, 18.30%, 8.73%, and 8.62%, respectively. A total of five types contained in PCO were found to have been removed including those with the highest percentage such as gamma-Linolenic AME and M Heptadecanoate while the content of M Linolenate and M Butyrate was reduced as indicated in Table 6. It was also discovered that seven types of new fatty acids were formed including those with the highest percentage such as M Tridecanoate.

3.2. T-history test for CO and WCO

The T-History test for the freezing process of CCO and WCCO produced a chart indicating the reduction in temperature followed by the
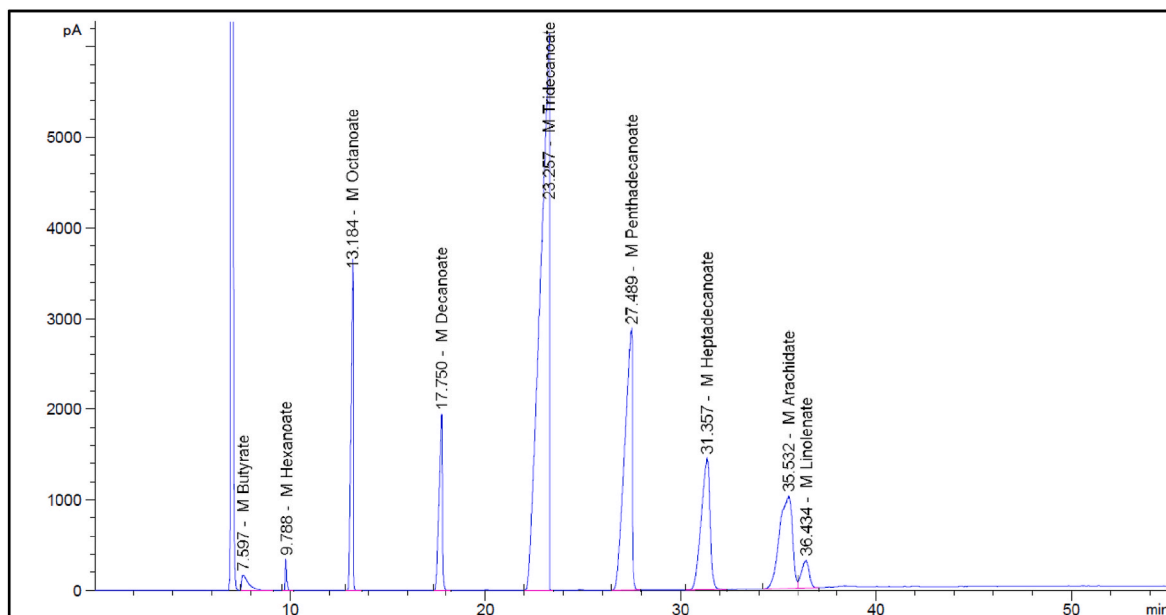
Fig. 1. Gas chromatography chart of CCO.

Table 1
Composition of fatty acids in CCO.

Peak Number	Retention Time	Name	Chemical Formula	Concentration (% Relative)
1	7.597	M Butyrate	$C_5H_{10}O_2$	1.00
2	9.788	M Hexanoate	$C_7H_{14}O_2$	0.37
3	13.184	M Octanoate	$C_9H_{18}O_2$	6.52
4	17.750	M Decanoate	$C_{11}H_{22}O_2$	5.81
5	23.257	M Tridecanoate	$C_{14}H_{28}O_2$	45.46
6	27.489	M Penthadecanoate	$C_{16}H_{32}O_2$	17.87
7	31.357	M Heptadecanoate	$C_{18}H_{36}O_2$	10.34
8	35.532	M Arachidate	$C_{21}H_{42}O_2$	10.71
9	36.434	M Linolenate	$C_{19}H_{32}O_2$	1.92

Table 2
Composition of fatty acids in WCCO.

| Peak Number	Retention Time	Name	Chemical Formula	Concentration (%Relative)
1	7.727	M Butyrate	$C_5H_{10}O_2$	2.94
2	13.042	M Octanoate	$C_9H_{18}O_2$	0.13
3	22.329	M Laurate	$C_{13}H_{26}O_2$	0.92
4	26.825	Myristolleic AME	$C_{15}H_{30}O_2$	1.26
5	31.009	M Heptadecanoate	$C_{18}H_{36}O_2$	36.09
6	35.392	M Arachidate	$C_{21}H_{42}O_2$	45.68
7	36.313	M Linolenate	$C_{19}H_{32}O_2$	12.58
8	37.510	*cis*-11,14-Eicosadienoic AME	$C_{21}H_{38}O_2$	0.29
9	39.748	M Tricosanoate	$C_{24}H_{48}O_2$	0.11
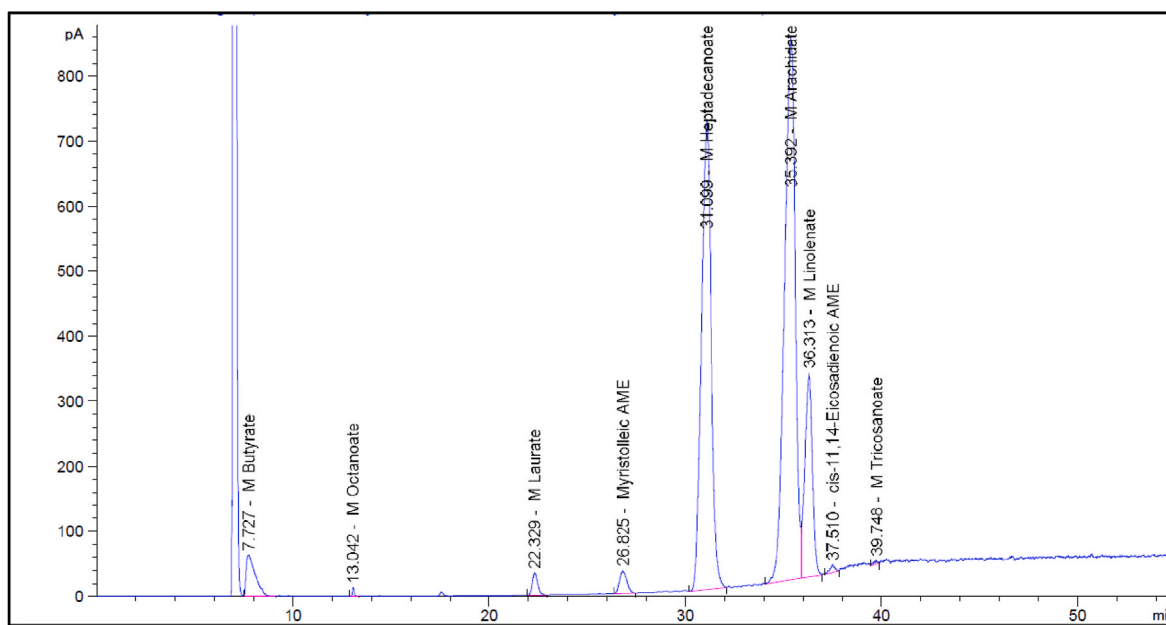
Fig. 2. Gas chromatography chart of WCCO.

Table 3

Comparison of the fatty acid composition in CCO and WCCO.

No	Name	Concentration (% Relative)	
		CCO	WCCO
1	M Butyrate	1.00	2.94
2	M Hexanoate	0.37	–
3	M Octanoate	6.52	0.13
4	M Decanoate	5.81	–
5	M Tridecanoate	45.46	–
6	M Penthadecanoate	17.87	–
7	M Heptadecanoate	10.34	36.09
8	M Arachidate	10.71	45.68
9	M Linolenate	1.92	12.58
10	M Laurate	–	0.92
11	Myristolleic AME	–	1.26
12	cis-11,14-Eicosadienoic AME	–	0.29
13	M Tricosanoate	–	0.11

beginning and end of the freezing as visually presented in the following Fig. 5. CCO was found to have reached subcooling at a temperature of 19 °C and increased to 20 °C where it started to freeze while WCCO experienced subcooling at 18 °C and started freezing at 19 °C. It was discovered that the freezing temperature of WCCO is slightly lower and this was associated with changes in the composition and type of fatty acid compounds in the materials.

3.3. Analysis of the differential scanning calorimetry test results for CO and WCO

Differential Scanning Calorimetry (DSC) test was conducted to determine the thermal properties in the form of phase change temperature and latent heat both in the freezing and melting processes. This section, therefore, analyzes and compares the results for CCO and WCCO as well as PCO and WPCO.

3.3.1. Differential scanning calorimetry test results of CCO and WCCO

The DSC test results for CCO showed that two stages of freezing occurred at temperatures of 33 °C–24.9 °C and 7.5 °C–0.5 °C while the melting process started from 8.2 °C to 25.3 °C with a peak of 22.7 °C. Moreover, the results presented in Table 7 indicated that the phase change temperature for the material to melt from solid to liquid was

8.2 °C–25.3 °C and the latent heat produced was 115.7 kJ/kg.

The DSC test results for WCCO also showed indicated two stages of freezing with the first recorded to have started at 25.3 °C and ended at 19.1 °C while the second was initiated at 7.0 °C and finished at 0.5 °C, as shown in Table 8. Table 8 also showed that the material started melting at 8.8 °C and finished at 24.9 °C.

3.3.2. Differential scanning calorimetry test results of PCO and WPCO

The results of DSC test for. PCO was shown in Table 9. The freezing

Table 4

Composition of fatty acids in PCO.

Peak Number	Retention Time	Name	Chemical Formula	Concentration (%Relative)
1	7.719	M Butyrate	$C_5H_{10}O_2$	3.67
2	22.407	M Laurate	$C_{13}H_{26}O_2$	0.50
3	26.945	Myristolleic AME	$C_{15}H_{30}O_2$	1.15
4	31.292	M Heptadecanoate	$C_{18}H_{36}O_2$	35.63
5	35.607	gamma-Linolenic AME	$C_{19}H_{32}O_2$	46.04
6	36.461	M Linolenate	$C_{19}H_{32}O_2$	12.74
7	37.615	cis-11,14-Eicosadienoic AME	$C_{21}H_{38}O_2$	0.28

Table 5

Composition of fatty acids in WPCO.

| Peak Number	Retention Time	Name	Chemical Formula	Concentration (%Relative)
1	7.641	M Butyrate	$C_5H_{10}O_2$	0.83
2	9.797	M Hexanoate	$C_7H_{14}O_2$	0.41
3	13.203	M Octanoate	$C_9H_{18}O_2$	7.03
4	17.776	M Decanoate	$C_{11}H_{22}O_2$	6.21
5	23.323	M Tridecanoate	$C_{14}H_{28}O_2$	48.41
6	27.566	M Penthadecanoate	$C_{16}H_{32}O_2$	18.30
7	31.381	cis-10-Heptadecenoic AME	$C_{18}H_{34}O_2$	8.73
8	35.460	M Arachidate	$C_{21}H_{42}O_2$	8.62
9	36.396	M Linolenate	$C_{19}H_{32}O_2$	1.48
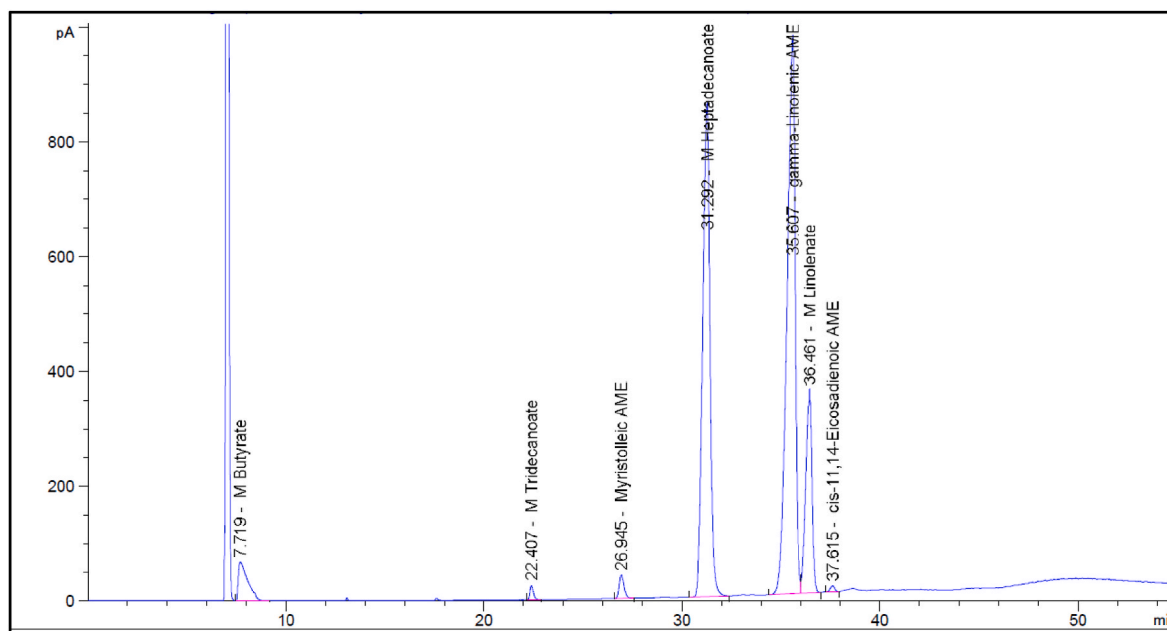
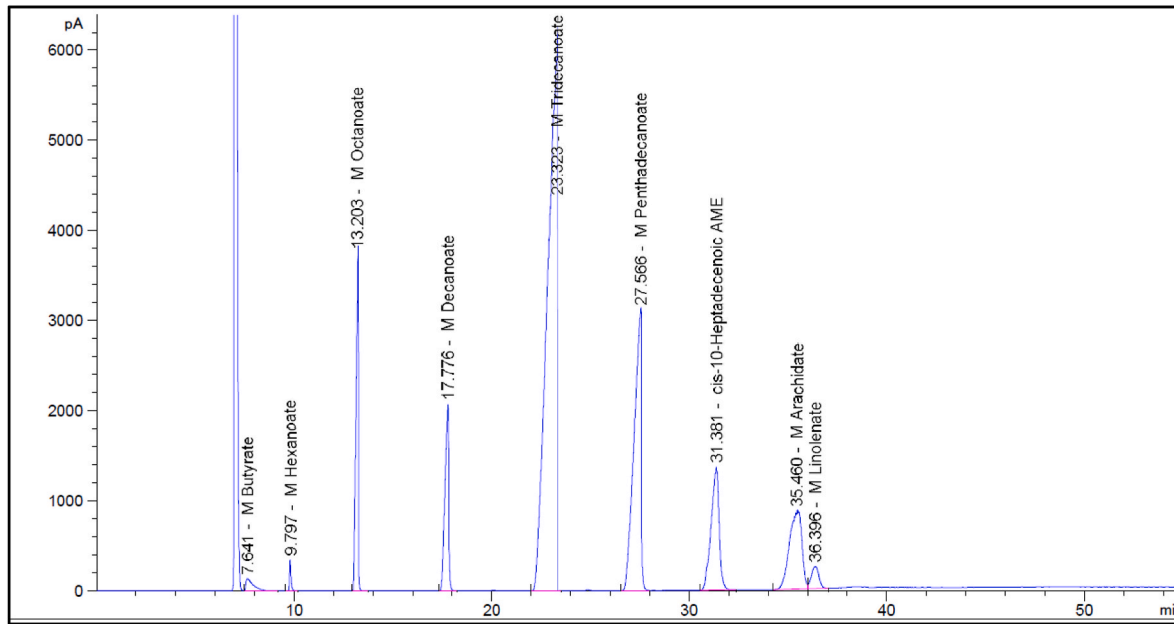**Fig. 3.** Gas chromatography chart of PCO.

Fig. 4. Gas chromatography chart of WPCO.

Table 6
Comparison of the fatty acid composition in PCO and WPCO.

No	Name	Concentration (%Relative)	
		PCO	WPCO
1	M Butyrate	3.67	0.83
2	M Laurate	0.50	–
3	Myristolleic AME	1.15	–
4	M Heptadecanoate	35.63	–
5	gamma-Linolenic AME	46.04	–
6	M Linolenate	12.74	1.48
7	cis-11,14-Eicosadienoic AME	0.28	–
8	M Hexanoate	–	0.41
9	M Octanoate	–	7.03
10	M Decanoate	–	6.21
11	M Tridecanoate	–	48.41
12	M Penthadecanoate	–	18.30
13	cis-10-Heptadecenoic AME	–	8.73
14	M Arachidate	–	8.62

Table 7
Phase change temperature and latent heat of CCO from DSC test results.

Phase Change	Onset °C	Peak °C	End °C	ΔH KJ/kg
Freezing	33	28	24,9	46,73
	7,5	4,3	0,5	22,38
Melting	8,2	22,7	25,3	115,70

Table 8
Phase change temperature and latent heat of WCCO from DSC test results.

Phase Change	Onset °C	Peak °C	End °C	ΔH KJ/kg
Freezing	25,3	20,4	19,1	7364
	7,0	5,8	0,5	19,43
Melting	8,8	22,1	24,9	97,76

Table 9
Phase change temperature and latent heat of PCO from DSC test results.

Phase Change	Onset °C	Peak °C	End °C	ΔH KJ/kg
Freezing	29,8	24	22,0	−15,69
	3,2	1,9	0,6	−5,18
Melting	5,2	0,9	6,1	45,60

The comparison of these results with the T-history test for PCO showed that there is no sign of freezing in the cooling process up to a temperature of 10 °C and this is the reason there were no initial and final freezing temperatures. A similar trend was also observed in the melting process and this means PCO is not suitable to be used as a PCM in the room cooling process.

The DSC test results for WPCO are shown in Table 10. It was discovered in Table 10 that there are three freezing processes and one melting process. The first freezing process was observed to have started at a temperature of 27.9 °C and ended at 23.9 °C, the second was between 23.9 °C and 20.9 °C, while the third was between 3.4 °C and 0.6 °C. The results also showed that the melting started at 5.2 °C and finished at 7 °C.
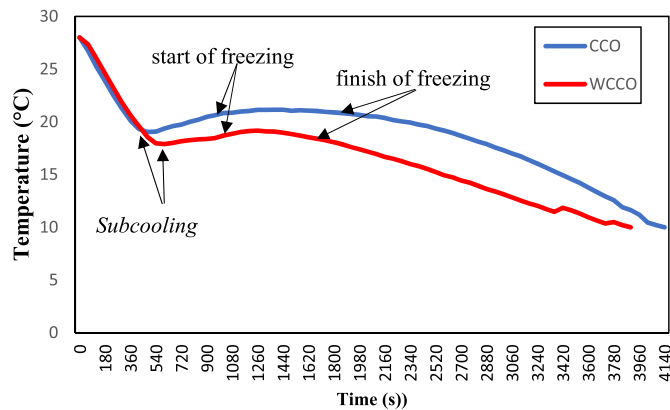

Fig. 5. T-History test for the freezing process of CCO and WCCO.

temperature of PCO started from the beginning of the first freezing at 29.8 °C and finished at 22 °C while the second freezing process initiated at 3.2 °C and ended at 0.6 °C. The table also shows that the melting process started at 5.2 °C and finished at 6.1 °C.

Table 10
Phase change temperature and latent heat of WPCO from DSC test results.

Phase Change	Onset °C	Peak °C	End °C	ΔH KJ/kg
Freezing	27,9	26,1	23,9	−9,80
	23,9	22,9	20,9	−1,02
	3,4	2,1	0,6	−4,82
Melting	5,2	6,5	7,0	43,68

The comparison of these results with the T-history test for WPCO showed that there is no sign of freezing in the cooling process up to a temperature of 10 °C and this is the reason there were no initial and final freezing temperatures. A similar trend was also observed in the melting process and this means WPCO is not suitable to be used as a PCM in room cooling process based on the DSC and T-history analyses.

3.4. CO and WCO thermal conductivity test

The application of PCM as thermal energy storage requires a process of absorbing and releasing heat and this is largely determined by the thermal conductivity of the PCM. This study, therefore, used TCi Thermal Conductivity Analyzer to determine the thermal conductivity value of cooking oil before and after use. It is important to note that the test was repeated 10 times for one sample and the results are summarized in Table 11 for all the cooking oil samples in the liquid phase including the CCO, WCCO, PCO, and WPCO. It was discovered that the overall thermal conductivity value of both unused and used cooking oil is not much different and was recorded to range from 0.151 W/m.K to 0.155 W/m.K. However, the value after the oil has been used is slightly higher than before use. The thermal conductivity of WCCO also increased by 2% compared to CCO and a similar trend was observed for WPCO and PCO. This is associated with changes in the composition and type of fatty acids as well as an increase in the water content. It is important to note that the values obtained in this study are slightly lower than those reported by Safira et al. (2020) [19] and El Sayeed et al. (2023) [20].

4. Conclusion

The repeated frying of the cooking oils used in this study was observed to have changed the type and composition of fatty acid compounds contained. This is indicated by the increase in the Methyl arachidate from 10.71% to 45.68% and Methyl heptadecanoate from 10.34% to 36.09% in WCCO. Meanwhile, some compounds decreased or disappeared such as the gamma-Linolenic AME in WPCO that reduced from 46.04% to 0%.

The findings showed that coconut cooking oil and waste coconut oil have the potential to be used as thermal energy storage to cool a room based on their thermal properties, especially the phase change temperature. It is important to note that WCCO is a very interesting material to be developed considering the similarities of its thermal properties with the CCO such as the 97.7 kJ/kg latent heat recorded for melting and the 0.155 W/m.K thermal conductivity. However, it has two weaknesses which include 1) a much lower thermal conductivity value compared to water, thereby, indicating the need for treatment to increase the value as well as 2) a quite large range of phase change temperature and the existence of subcooling.

Credit author statement

Muhammad Irsyad: Develop of conceptualization involve: ideas; formulation or evolution of overarching research goals and aims, and data analysis. Amrizal: Review content and writing, and improve it. Harmen: Development or design of methodology; creation of models. Amrul: Formal analysis. M Dyan Susila ES: Compile references and write draft articles. Ahmad Rizki Diva Putra: Data collecting, create of graphs

Table 11
Thermal conductivity values of cooking oil and waste cooking oil.

NO	Sensor	Thermal conductivity (W/m.K)			
		CCO	WCCO	PCO	WPCO
1	H561	0.151	0.155	0.151	0.153
2	H561	0.150	0.155	0.151	0.154
3	H561	0.151	0.155	0.152	0.154
4	H561	0.151	0.155	0.151	0.155
5	H561	0.151	0.156	0.151	0.154
6	H561	0.152	0.156	0.151	0.154
7	H561	0.152	0.155	0.151	0.154
8	H561	0.153	0.155	0.151	0.154
9	H561	0.154	0.155	0.151	0.153
10	H561	0.154	0.155	0.152	0.155
Average		**0.152**	**0.155**	**0.151**	**0.154**

and tables

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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