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Green Concept in Preparation of Biodiesel by Decarboxylation of Fatty Acids Derived from Waste Coconut and Rubber Seed Oils

U. S. K. Weliwegamage[1,*], S. Sotheeswaran[1], H. I. C. De Silva[2], D. G. G. P. Karunaratne[3] and P. H. Gamage[1]

[1]*College of Chemical Sciences, Institute of Chemistry Ceylon, Rajagiriya, Sri Lanka*
[2]*Department of Chemistry, University of Colombo, Colombo, Sri Lanka*
[3]*Department of Chemical and Process Engineering, University of Peradeniya, Peradeniya, Sri Lanka*

[*]weliwegama@ichemc.edu.lk

Abstract

Green production of diesel was carried out using waste coconut oil and rubber seed oil. Experiments were carried out using preliminary apparatus constructed in house as well as using a high temperature pressure reactor. Acid values of oil samples were determined before and after the decarboxylation process. Decarboxylation of hydrolysed waste coconut oil produced the hydrocarbons, nonane (15.60% w/w), decane (46.38% w/w), undecane (23.2% w/w), dodecane (1.34% w/w) and tridecane (0.36% w/w). Decarboxylation of non-hydrolysed waste coconut oil when reacted at 350 °C using Pd/C catalyst resulted in hexadecane, undecane, tridecane and pentadecane. Decarboxylation of non-hydrolysed rubber seed oil resulted in 6-dodecene, 5-undecene and tridecane, while hydrolysed rubber seed oil resulted in tetradecane, 2-tetradecene, 1-hexadecene, pentadecane and 6-tetradecyne. Many hydrocarbon compounds produced are corresponding to the diesel range of C_{10}-C_{22} indicating the possibility of using these products in diesel fuel applications after further testing. The decrease in the acid value of reaction mixtures containing waste oils after decarboxylation was used as an indicator for the conversion or the decarboxylation. The process employed in the production of biodiesel was a simple and environmentally friendly green method supported by catalysis and did not involve any toxic chemicals, derivatizing agents or harmful solvents.

Keywords: Biodiesel, Catalysis, Decarboxylation

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Introduction

Due to the adverse effects on the physical environment and biosphere, the use of petroleum fuels is needed to be limited. In addition to their contribution to greenhouse gas (GHG) emissions and climate changes, the impurities in petroleum fuels, including sulfur, nitrogen substances, aromatics and lead, contribute to severe atmospheric pollution. On the other hand, petroleum is a depleting resource, which will not be replenished once used up.

Scientists have forecasted that remaining global petroleum resources will be sufficient only for another few decades in the current rate of consumption (Hubbert, 1956; Deffeyes, 2003). Therefore, possible energy alternatives are much investigated. Among such alternatives, biodiesel (Huang et al., 2012), bioethanol (Thangavelu et al., 2016), biogas (Ray et al., 2013), and syngas (Gupta et al., 2010) have attracted much attention. Such energy alternatives are renewable, accompany no significant amounts of sulfur and nitrogenous compounds. They contribute to lower GHG emissions as compared to petroleum products and less harmful to the atmosphere during combustion (Nabi et al., 2006; Kathirvelu et al., 2017). Further, as they do not come from earth's geological carbon deposits, there is no contribution to a net increase in atmospheric carbon. However, with many advantages, a few significant disadvantages are associated with biofuels, such as biodiesel and bioethanol, which have limitations on their application as transportation fuel. The water content, less energy content, oxygenated structures, and high freezing and cloud points are given in Table 1 (Nabi et al., 2006; Elfasakhany, 2019).

Due to the presence of oxygen in their chemical structures, biodiesel and bioethanol have some degree of polarity. They attract moisture due to this fact. Due to the same reason, they are more reactive compared to petroleum fuels. They can damage engine parts made up of rubber due to their rubber solvent properties. Furthermore, corrosion of engine components is also possible due to the moisture content associated with them (Anguebes-Franseschi et al., 2019). Moreover, energy values of biodiesel and bioethanol are less compared to petroleum fuels, such as petroleum diesel and gasoline (Table 1). Due to these limitations, using 100% pure biodiesel or bioethanol in automobiles is not feasible. They should be blended with fossil fuels, or alternatively, engines of automobiles should be modified (Celik et al., 2008).

Green diesel, which is also called renewable diesel, is chemically hydrocarbons unlike biodiesel, which contains the fatty acid methyl esters. It has similar energy content as the petroleum diesel and being free of contaminants such as sulfur and aromatic compounds adding more value to renewable diesel over biodiesel. Renewable diesel has better emission characteristics over petroleum diesel (Moser, 2009; Douvartzides et al., 2019). Biodiesel types can be used in modern automobile engines in 100% quantity (R100) without blending with petroleum diesel (Douvartzides et al., 2019). No solidification occurs at cold climates due to their lower cloud points.

Green diesel can be produced using natural plant and animal fatty acids as feed stock (Douvartzides et al., 2019; Amin, 2019; Vignesh et al., 2021). As waste plants and animal oils can be used as raw materials in the production, it is economical and ecofriendly, providing a solution to waste oil, which is a threat to the environment. Green diesel further has some distinct advantages, including high cetane number, decreased cloud point, lower levels of NO_x, compared to biodiesel (Phoon et al., 2017). This makes green diesel a more promising candidate as an alternative to fossil fuels. Plant oils contain a significant percentage of oxygen, which needed to be removed in the production of green or renewable diesel. There are two major methodologies used for this purpose.

Hydrodeoxygenation involves removal of oxygen as a water molecule. This requires the presence of a catalyst, high temperature and high hydrogen pressures. Various studies have been conducted to convert plant oils to hydrocarbons through this process (Morgan et al., 2012; Santillan-Jimenez et al., 2014; Ding et al., 2015; Arun et al., 2015; Guan et al., 2016; Ameen et al., 2017; Jenišťová et al., 2017; Heriyanto et al., 2018). Hydrodeoxygenation, which produces hydrocarbon, H_2O and CO, takes place as given below (Furimsky, 2000; Stepacheva et al., 2016).

$$C_nH_{2n+1}COOH + H_2 \rightarrow C_nH_{2n+2} + H_2O + CO$$

In decarboxylation, the carbonyl oxygen in the fatty acid is removed as CO_2 using a catalyst as shown below:

$$R{-}COOH \xrightarrow{\text{soda lime(CaONaOH)}} RH + CO_2$$

Investigation is carried out on producing biodiesel via decarboxylation (Sari, 2013; Aliana-Nasharuddin et al., 2020; Edeh et al., 2021). Decarboxylation reactions are thermodynamically favourable due to the increase of entropy during reaction with a stable gaseous product, CO_2. Even though both the processes serve the same purpose, production of CO during hydrodeoxygenation can have an impact on the catalyst performance. Also, the use of large quantity of hydrogen makes the process expensive as well as unsafe due to the explosive nature of hydrogen. Therefore, decarboxylation is the preferred process. Production of hydrocarbon through decarboxylation was the main objective of this research, which focused on the preparation of green diesel from fatty acids originating from waste coconut oil and rubber seed oil. The three types of fuels, petroleum diesel, biodiesel and biodiesel are compared for their properties as given in Table 1.

Experimental

Instrumentation

In order to conduct experiments at higher temperatures and pressures, the TOPT-H reactor shown in Figure 1 was employed. Specifications of the reactor are given in Table 2.

Figure 1. TOPT-50 mL high pressure reactor used in advanced experiments.

Gas chromatography-mass spectrometry (GC-MS) analysis of products

The products obtained by decarboxylation of waste coconut oil with soda lime were analysed with GC-MS at the Department of Chemistry, University of Colombo. It was equipped with an HP-5MS column (30 μm × 250 μm × 0.25 μm).

Materials

Raw materials

As sources of fatty acids, two plant oils, namely, waste coconut oil and rubber seed oil, were used. Waste coconut oil was collected from some restaurants and hotels, located in Colombo, Sri Lanka, while rubber seed oil was extracted using dry rubber seeds obtained from local rubber plantations.

Table 1. Properties of petroleum (Ultra Low Sulfur Diesel, ULSD), biodiesel (Fatty Acid Methyl Ester, FAME) and green diesel (Source: Fuels comparison chart, National Renewable Energy Laboratory, US Department of Energy Website http://www.eere.energy.gov).

Property	Petroleum (ULSD)	Biodiesel (FAME)	Biodiesel
% Oxygen	0	1	0
Specific gravity	0.84	0.88	0.78
Sulfur, ppm	<10	<1	<1
Heating value, MJ/kg	43	38	44
Cloud point, °C	-5	-5 to +15	-10 to +20
Distillation, °C	200-350	340-355	265-320
Cetane	40	50-65	70-90
Stability	Good	Marginal	Good

Table 2. Technical specifications of the reactor.

Parameter	Maximum value/range
Volume	50 mL
Working pressure	12.5 MPa
Design temperature	10 MPa
Working temperature	400 °C - 450 °C
Temperature control accuracy	$\pm$ 1 °C
Stirring speed	10 - 000 rpm
Motor power	80 W
Electric heating rated power	1 kW
Working environment	Ambient temperature 5 - 35 °C; relative humidity $\leq$ 85%; surrounding medium does not contain conductive dust and corrosive gases.

Chemicals and catalysts

Soda lime, alumina, KOH, hexane, ethanol, isopropyl alcohol, glacial acetic acid purchased from Sigma-Aldrich were of 99% purity and used without further purification. The catalyst used for the decarboxylation process was palladium on carbon (5 w/w%), which was purchased from Sigma Aldrich. Hydrogen gas, purchased from Ceylon Oxygen Ltd., was used to activate the catalyst and to saturate unsaturated hydrocarbons.

Methods

Decarboxylation of oils with preliminary apparatus

The reaction vessel contained the reactants and catalysts, which provided space for them to react with each other. It also contained a thermometer to check and control reaction temperature. The reaction vessel was often heated, and products were collected in the vapour phase. Heating was conducted with a heating mantle which provided a constant temperature throughout the reaction vessel. The tube "**a**", extended from the reaction vessel was shorter, and used to collect gaseous products. However, this tube "**a**" extended into the catalyst vessel was long enough to reach the catalyst bed. This allowed unreacted reactants in the vapour phase to further react and form products. The catalyst chamber was heated with a heating mantle, mildly compared with reaction vessel, to keep the products in vapour form, which then was passed through tube "**b**" having a shorter stem in the chamber. This tube was passed through a condenser to convert gaseous products into a liquid and collected at the collection vessel. The collection vessel was sealed as the product was volatile.

Decarboxylation of waste coconut oil with the high-pressure reactor using Pd/C as the catalyst

The acid value of waste coconut oil collected from households and restaurants was

Table 3. Experimental conditions for decarboxylation of waste coconut oil with 100% soda lime.

Sample	Oil (g)	Soda lime (g)	Temperature (°C)	Pressure (MPa)	Agitation speed (rpm)
WCO 1	45.57	5.00	150	1.2	250
WCO 2	45.67	5.00	200	1.2	250
WCO 3	45.58	5.00	250	1.2	250

Table 4. Experimental conditions for decarboxylation of waste coconut oil with soda lime:alumina 1:1 ratio.

Sample	Oil (g)	Soda lime (g)	Temperature (°C)	Pressure (MPa)	Agitation speed (rpm)
WCO 1	45.48	5.00	150	1.2	250
WCO 2	45.56	5.00	200	1.2	250
WCO 3	45.54	5.00	250	1.2	250

Table 5. Experimental conditions for decarboxylation of waste coconut oil with 100% alumina.

Sample	Oil (g)	Soda lime (g)	Temperature (°C)	Pressure (MPa)	Agitation speed (rpm)
WCO 1	45.72	5.00	150	1.2	250
WCO 2	45.57	5.00	200	1.2	250
WCO 3	45.81	5.00	250	1.2	250

determined using KOH, ethanol and diethyl ether as analytical reagents, and 1% (w/v) phenolphthalein as the indicator. The acid value was tested with standard AOAC 940.28 method (AOAC International, 1999). Oil was filtered prior to experiments to eliminate particulate matter. The sample volume of waste coconut oil used for decarboxylation was 50 mL and 0.050 g Pd/C (5% w/w) was used as the catalyst. The pressure was a fixed at 1.2 MPa during experiments, and the temperature was varied as 150 °C, 200 °C, 250 °C, 300 °C and 350 °C in different decarboxylation trials.

Water was eliminated from the sample by adding anhydrous Na_2SO_4 prior to decarboxylation. The sample was agitated at 250 rpm. The reaction was carried out for 2.0 h after the pre-determined temperature was attained. The product was recovered by isolating the catalyst. The mixture of products and the catalyst was centrifuged followed by several filtrations to separate the product from the catalyst. The acid value of each sample was tested after the product was recovered.

The product recovered was analysed by GC-MS. The oven temperature of the instrument was programmed as follows: 2 min hold at 80 °C, 10 °C min^{-1} ramp to 300 °C, 10 min hold at 300 °C. The detector temperature was maintained at 300 °C. Samples of 1 μL were injected into the column with a 50:1 split ratio. The results obtained were analysed using the library.

Decarboxylation of waste coconut oil with soda lime and alumina as a catalyst mixture

Experiments were conducted to carry out decarboxylation of waste coconut oil in the presence of mixtures of soda lime and alumina (Al_2O_3) at 150 °C, 200 °C and 250 °C, and 1.2 MPa pressure. The acid value of each product was determined. Table 3, 4 and 5 show experimental conditions for three different soda lime:alumina ratios used in the decarboxylation process.

Decarboxylation of rubber seed oil

Decarboxylation of rubber seed oil was carried out in the preliminary apparatus. Rubber seeds were de-shelled, dried, crushed and oil was extracted using Soxhlet apparatus with hexane as the solvent. The acid value was

determined, in triplicate, using Standard AOAC (1999) method, and the average values were taken into consideration.

Prior to adding to the reactor, a part of the oil was hydrolysed using ethanolic KOH to yield free fatty acids. Hydrolysis was carried out at 60 °C for 2.0 h. After alkaline hydrolysis, the mixture was acidified using glacial acetic acid. The acid value of the hydrolysed rubber seed oil was determined using the same method mentioned previously.

In the reaction vessel, the combination of soda lime was added along with alumina, and the same was added in the catalyst chamber. The mixture was heated, and the temperature was recorded. Catalytic compositions were varied as shown in Tables 6 and 7. Both hydrolysed and non-hydrolysed rubber seed oils were used for the decarboxylation process. The size of the oil sample used was 50.00 mL, and decarboxylation was carried out at a fixed temperature of 235 °C.

The products were collected at the collection vessel and analysed by GC-MS using experimental conditions given below: The initial oven temperature was 80 °C held for one minute, and then increased to 180 °C at 10 °C min^{-1} and held for 1 min. Then the temperature was increased to 250 °C at a rate of 4 °C min^{-1} and held at for 5 min. A sample of 1 μL was injected at the injector temperature of 325 °C. The flow rate of the carrier gas He was kept at 0.9 mL min^{-1}. The total runtime of the process was 34.5 min.

Table 6. Decarboxylation of non-hydrolysed rubber seed oil (RSO).

Sample No.	Soda lime, w/w%	Alumina, w/w %
RSO1	100	0
RSO2	75	25
RSO3	50	50
RSO4	25	75
RSO5	0	100

Table 7. Decarboxylation of hydrolysed RSO.

Sample No.	Soda lime, w/w%	Alumina, w/w %
RSH1	100	0
RSH2	50	50
RSH3	0	100

Results and Discussion

Acid value (AV) determination of oils

Acid value determination of both waste coconut and rubber seed oils was carried out before and after decarboxylation. The acid value (AV) was determined with the standard equation,

$$\text{AV} = \frac{V \times N \times 56}{W} \quad (1)$$

where V is the volume of ethanolic KOH added, N is the normality of the ethanolic KOH solution, W is the mass of oil taken (g), and 56 is the equivalent mass of KOH.

The acid value of the waste coconut oil sample before hydrolysis was found to be 78.32±0.32 mg/KOH. The percentage of free fatty acids (FFA) was calculated as acid value×0.503 = (78.32±0.32)×0.503 = 39.39±0.16. According to literature, the acid value of unused coconut oil is 0.37 mg/KOH. Therefore, the percentage of FFA in unused oil is 0.37×0.503 = 0.19. It is thus clear that the percentage of FFA in unused coconut oil is very much lower than that of waste coconut oil. The reason for this may be the dissociation of fatty acids from triglycerides during the frying process, where heat absorbed can dissociate triglycerides to form free fatty acids. The acid value of the waste coconut oil sample after hydrolysis was 162.70±0.16 mg/KOH, and the percentage of free fatty acids was acid value×0.503 = (162.70±0.16)×0.503 = 81.49±0.08.

Hydrolysis of waste coconut oil

The fatty acid percentages of waste coconut oil before and after hydrolysis were 39.39±0.16 and 81.49±0.08, respectively. These values

show that the acid value has substantially increased after hydrolysis. The above calculations show that hydrolysis with KOH/EtOH, the triglyceride (triacylglycerol) dissociates into potassium salts of the fatty acids and glycerol. The type of potassium salts of fatty acids depends on the nature of fatty acids that form the triglyceride. That can either be same or different depending on chain lengths of R_1, R_2 and R_3 (Figure 2). Upon acidifying the fatty acid salts, a mixture of fatty acids is yielded, and subsequently, the acid value is increased. Therefore, the hydrolysed waste coconut oil sample with a higher amount of free fatty acids was used for decarboxylation.

Decarboxylation products of hydrolysed waste coconut oil

The products received from decarboxylation of waste coconut oil at three different temperatures (250 °C, 200 °C and 150 °C), were analysed for the presence of hydrocarbons. The product received at 250 °C (WCO 1) showed hydrocarbons in its GC-MS profile. The GC-MS results given in Figure 3, and the hydrocarbons produced are shown in Table 8.

According to the GC-MS results and library comparison, nonane, decane, undecane, dodecane and tridecane are present in WCO 1. The carbon chain lengths of these hydrocarbons are 9, 10, 11, 12 and 13, respectively. The percentage areas could be used as a measure of the abundance of the respective hydrocarbon. According to GC-MS results of WCO 1, the most abundant hydrocarbon is decane with a percentage peak area of 46.38. The most abundant fatty acid in coconut oil is lauric acid [$CH_3(CH_2)_{10}COOH$], which is 48.90 % of the total fatty acid content. According to the decarboxylation reaction given in Figure 4, lauric acid should be converted to C_{11} hydrocarbons.

However, in the above experiment, the main component was decane which is a C_{10} hydrocarbon.

Decarboxylation of non-hydrolysed waste coconut oil with the high-pressure reactor and Pd/C

The acid value of the waste coconut oil sample, taken from the same batch which was used in the preliminary apparatus, before decarboxylation is 78.32±0.32 mg/KOH. Table 9 shows the acid values of the products recovered at different temperatures. Figure 5 graphically depicts how the acid value has decreased with the temperature of decarboxylation.

Figure 5 indicates that the acid values decreased when the decarboxylation temperatures were increased. Acid value correlates to the amount of free fatty acids present in an oil sample. This illustrates that the amount of free fatty acids was decreased as the decarboxylation temperature was increased, which in turn indicates that the decarboxylation has proceeded during the reaction. However, the GC-MS results indicate that only the products obtained at 300 °C and 350 °C show the presence of hydrocarbons (Figures 6 and 7). Table 10 shows the retention time and percentage peak areas of hydrocarbons present in the products.

The hydrocarbons obtained, undecane, tridecane, pentadecane and hexadecane correlate to the fatty acids present in coconut oil.

Decarboxylation of waste coconut oil with soda lime and alumina as a catalyst mixture

A new batch of waste coconut oil with an acid value of 56.32±0.64 was employed in this experiment. Acid values of decarboxylated products at temperatures 150 °C, 200 °C and 250 °C with the presence of 100% soda lime, 1:1 soda lime to alumina and 100% alumina, and their product recovery percentages are given in Table 11. Figure 8 graphically represents the variation of acid values of the products.

The lowest acid value of 2.99±0.03 given in Figure 8 corresponds to the product obtained at 250 °C with 1:1 soda lime:alumina

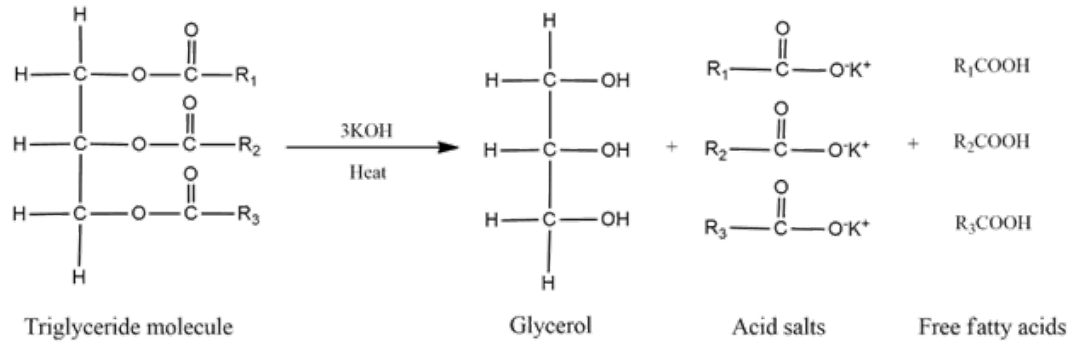

Figure 2. Hydrolysis process of a model fatty acid.

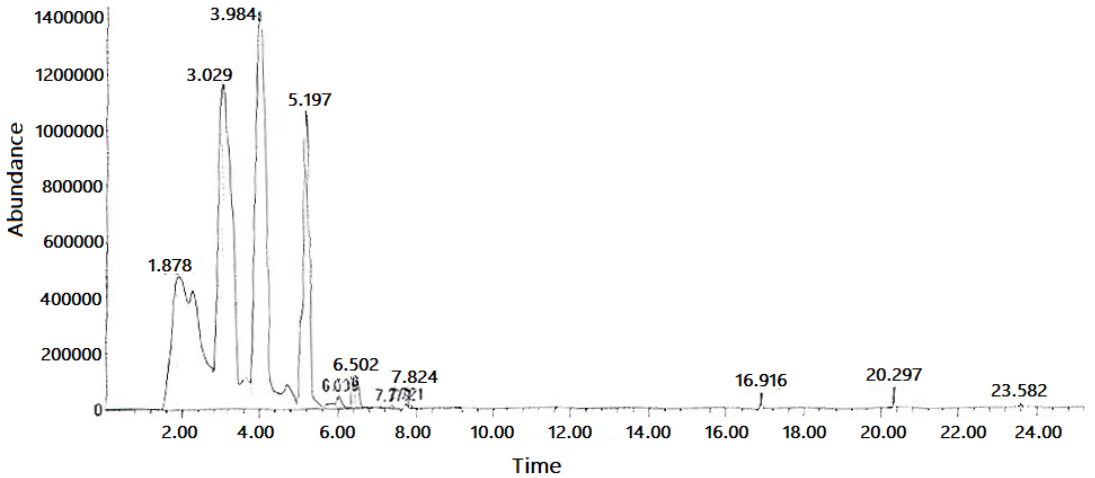

Figure 3. GC-MS recording of the products received after decarboxylation of WCO 1.

Table 8. Hydrocarbons present in WCO 1.

Hydrocarbon	C number	Retention time	Peak area (%)
Nonane	9	3.029	15.60
Decane	10	3.984	46.38
Undecane	11	5.197	23.20
Dodecane	12	6.502	1.34
Tridecane	13	7.824	0.36

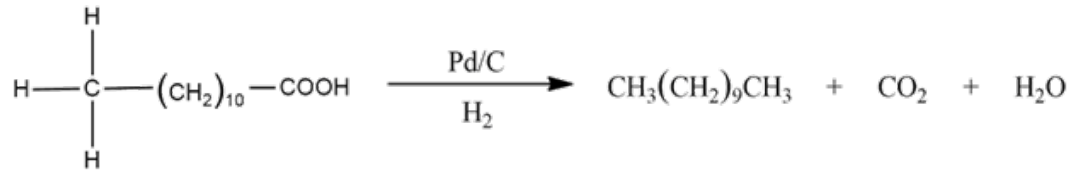

Figure 4. Decarboxylation of lauric acid.

Table 9. Acid values of decarboxylated products of non–hydrolysed waste coconut oil at different decarboxylation temperatures

Decarboxylation Temperature (°C)	Acid value (mg g^{-1})
150	62.64±0.32
200	28.79±0.32
250	11.03±0.31
300	10.29±0.38
350	8.58±0.50

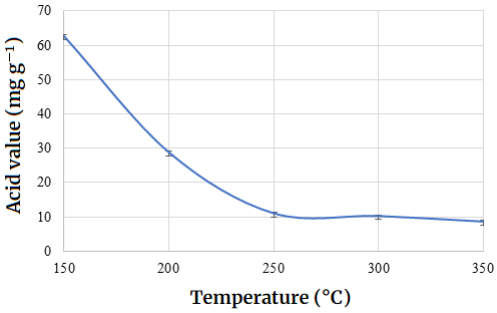

Figure 5. Variation of acid value of the products with decarboxylation temperature.

ratio. Therefore, it can be determined that decarboxylation process was optimum when soda lime:alumina ratio was 1:1 at a temperature of 250 °C. Low acid value correlates to the low content of free fatty acids, and therefore, it can be assumed that most of the fatty acids could have been converted to hydrocarbons. In general, under all conditions, acid values of the products are lower than that of the initial value (56.32 ± 0.64). This is an indication of the decarboxylation has taken place.

Recovery of the hydrocarbon products and soda lime alumina mixture

Hydrocarbon product recovery percentages under all conditions were calculated by,

$$\frac{\text{Initial mass of the sample-Final mass of the product}}{\text{Initial mass of the sample}} \times 100\%$$

Recovery percentages calculated using the above relationship are given in Table 11. The highest recovery percentage according to the results obtained is 96.87%. This was obtained at 325 °C, when alumina was employed as the catalyst. However, according to Table 11 and Figure 8, the highest amount of hydrocarbons is present when 1:1 mixture of soda lime and alumina was employed as the catalyst mixture, at 250 °C. Table 11 shows that the recovery percentage is 88.46 at these conditions. Therefore, it can be concluded that the optimum decarboxylation conditions are at 250 °C, with soda lime:alumina 1:1 mixture. Product recovery was much more feasible in catalyst mixtures of soda lime and alumina than when soda lime was used alone. Soda lime was found to be coagulated with the product, which made it difficult for the soda lime and product to be separated. However, addition of alumina supported to overcome that problem as the soda lime and alumina mixture was easily separated from the product.

Decarboxylation of rubber seed oil

GC-MS analysis showed presence of several hydrocarbons in the decarboxylated mixtures of hydrolysed and non-hydrolysed rubber seed oil. The hydrocarbons, 6-dodecene, 5-undecene and tridecane were present in the decarboxylated product of non-hydrolysed rubber seed oil, in the presence of 25% alumina and 75% soda lime. The percentage peak areas are given in Table 12. Other decarboxylated mixtures of non-hydrolysed rubber seed oil did not show presence of any hydrocarbons. Decarboxylated mixtures of hydrolysed rubber seed oil samples showed presence of the hydrocarbons given in Table 13.

The highest hydrocarbon percentage is for 6-dodecene found in non-hydrolysed rubber seed oil. Further, the data shown above indicates the presence of unsaturated hydrocarbons in the products obtained. This can be attributed to the fact that rubber seed oil is mainly composed of unsaturated fatty acids. Percentage peak area can be considered as an indicator to quantitatively compare the hydrocarbons. These experiments indicate

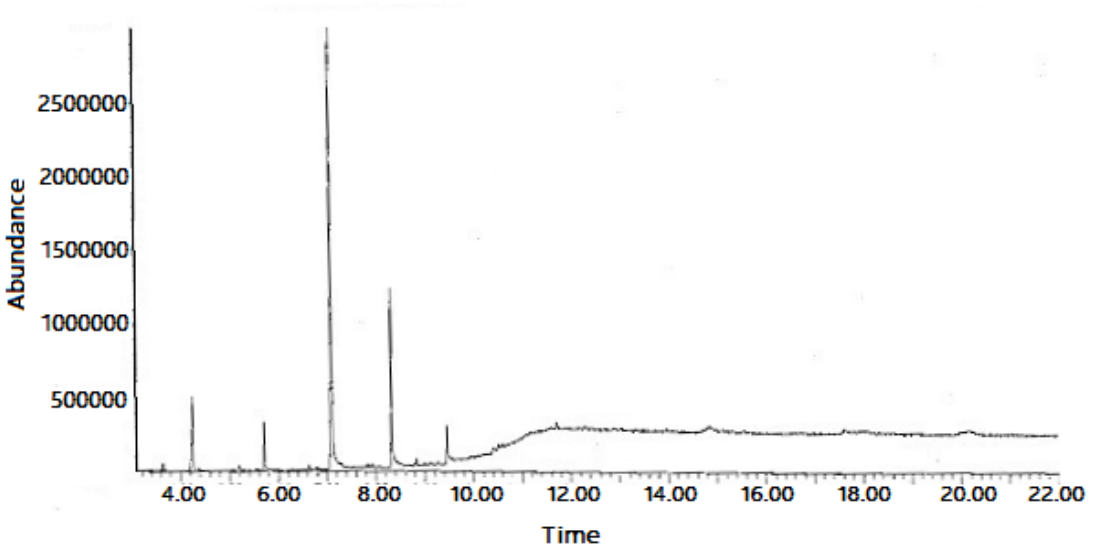

Figure 6. GC-MS results of products after decarboxylation of waste coconut oil with the high-pressure reactor and Pd/C at 300 °C.

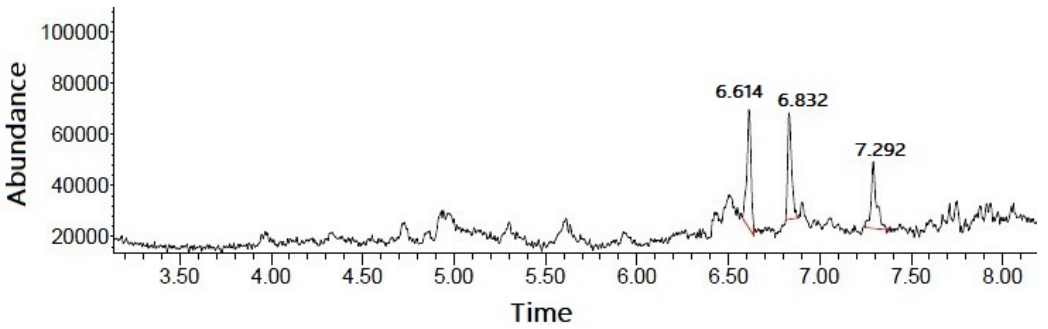

Figure 7. GC-MS results of products after decarboxylation of waste coconut oil with the high-pressure reactor and Pd/C at 350 °C.

Table 10. Hydrocarbons obtained at 300 °C and 350 °C, after decarboxylation of waste coconut oil with the high pressure reactor and Pd/C.

Temperature (°C)	Hydrocarbon	C chain length	Retention time (s)	Percentage peak area
300	Hexadecane	16	7.295	6.44
350	Undecane	11	3.636	0.50
350	Tridecane	13	5.204	0.39
350	Pentadecane	15	6.635	0.43

that decarboxylation of rubber seed oil in the presence of soda lime and alumina can be employed to produce hydrocarbons in the diesel range.

Conclusion

The decarboxylation of waste coconut oil and rubber seed oil results in a large number of hydrocarbons in the diesel fuel range ($C_{10}-C_{22}$), depending on the nature of the

Table 11. Acid values of products obtained by decarboxylation of waste coconut oil at 150 °C, 200 °C and 250 °C with the catalytic compositions of 100% soda lime, 1:1 soda lime to alumina and 100% alumina, and their percentage product recoveries.

Catalytic Composition	100% Soda lime		1:1 Soda lime:Alumina		100% alumina	
Temperature (°C)	Acid value/mg KOH/1 g oil	% Product recovery	Acid value/mg KOH/1 g oil	% Product recovery	Acid value/mg KOH/1 g oil	% Product recovery
150	13.62 ± 0.32	68.42	7.24 ± 0.64	83.24	14.12 ± 0.32	91.68
200	6.80 ± 0.05	71.42	3.85 ± 0.64	81.42	8.8 ±0.64	94.89
250	7.50 ± 0.32	65.34	2.99 ± 0.03	88.46	7.62±0.32	96.87

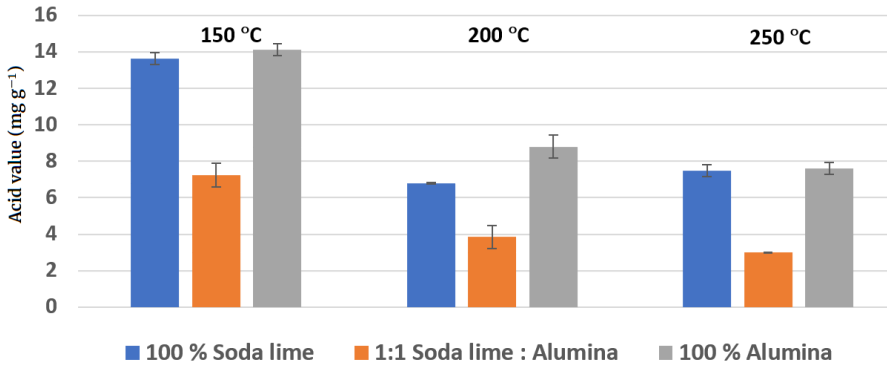

Figure 8. Acid values of decarboxylated products at 150 °C, 200 °C and 250 °C in the presence of 100% soda lime, 1:1 soda lime:alumina and 100% alumina.

Table 12. Hydrocarbons present in decarboxylated products in non-hydrolysed rubber seed oil in the presence of 25% alumina and 75% soda lime.

Hydrocarbon	Carbon chain length	Percentage peak area
6-Dodecene	12	57.61
5-Undecene	11	19.9
Tridecane	13	12.03

Table 13. Hydrocarbons present in decarboxylated mixtures in hydrolysed rubber seed oil.

Hydrocarbon	Carbon chain length	Percentage peak area
Tetradecane	14	4.46
2-Tetradecene	14	6.48
1-Hexadecene	16	0.41
5-Tetradecene	14	2.39
Pentadecane	15	7.9
6-Tetradecyne	14	0.3

substrate and decarboxylation conditions (temperature and pressure). One limitation is the small quantity of oil (50 mL) which can be placed in the reactor chamber, results in small quantities of products, where quantitative analysis of products makes it difficult. The process of producing biodiesel is a simple environmentally friendly process, which does not involve any toxic reagents or products.

Acknowledgement

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