Journal of Engineering Science and Technology
ICIST2024, Vol. 20, No. 5 (2025) 37 - 49

ULTRASONIC WAVE TECHNIQUE FOR CONVERTING USED COOKING OIL INTO BIODIESEL USING COAL LIGNITE CATALYST

MUSTAFA[1,*], PRAMILA TAMUNAIDU[2,3], MUH. IRWAN[1]

[1]Departemen Of Chemical Engineering, Politeknik Negeri Samarinda, Jalan Dr.Ciptomangenkusumo, Kampus Gunung Panjang 75131, Samarinda, East Kalimantan Province, Indonesia
[2]Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia Jalan Sultan Yahya Petra, 54100 UTM Kuala Lumpur, Malaysia
[3]Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 UTM Kuala Lumpur, Malaysia
*Corresponding Author: mustafa@polnes.ac.id

Abstract

This study was conducted to produce biodiesel from used cooking oil using lignite coal catalysts with the help of ultrasonic waves. Ultrasonic waves can be used to increase reaction conversion and accelerate reaction rates. The purpose of this study was to determine the effect of the use of ultrasonic waves on exposure time and temperature in the transesterification process in the conversion of used cooking oil into biodiesel. Used cooking oil and methanol (1:3) were transesterified at a temperature of 60°C with variations in ultrasonic time (25, 30, 35, and 40 minutes) and ultrasonic temperature (40, 45, 50, 55, and 60℃) using 7 grams of lignite coal catalyst with the help of ultrasonic waves with a frequency of 42 kHz. The best result for ultrasonic time is 35 minutes with the highest yield of 96.55% obtained density at a temperature of 40 ^oC 857.2 kg/m^3, kinematic viscosity at a temperature of 40^oC 3.38 mm^2/s, water content 0.032%, acid number 0.43 mgKOH/g, free fatty acid 0.12%, while for ultrasonic temperature the best result is at 50 ^oC with the highest yield of 99.21% obtained density at a temperature of 40 ^oC 857.7 kg/m^3, kinematic viscosity at a temperature of 40 ^oC of 3.57 mm^2/s, water content 0.047%, acid number 0.37 mgKOH/g. The results obtained, namely density at 40^oC, kinematic viscosity at 40^oC, water content, acid number, and free fatty acids have met the SNI 7182:2015 standard.

Keywords: Biodiesel, Catalyst, Lignite rank coal, Ultrasonic waves, Used cooking oil.

1. Introduction

The shape of a projectile is generally selected on the basis of combined Indonesia plays a strategic role in the global food system through plantations and agriculture. According to the Central Statistics Agency (BPS), in 2022, the area of rice fields will reach 7.46 hectares involving around 27.68 million farmers. This makes Indonesia the main producer of several world strategic agricultural commodities such as palm oil. Indonesia became the world's largest producer of palm oil in 2019, and one of its products is cooking oil.

Used cooking oil commonly called used cooking oil is waste oil that comes from the remains of household cooking oil use, especially from restaurants and the food industry. During the heating process (frying) for a certain period and repeatedly, the result is that used cooking oil contains several compounds that are dangerous to human health due to the hydrolysis reaction that begins when food containing water is fried in hot oil.

Long-term and repeated use of cooking oil can cause various fatal diseases [1]. Used cooking oil has great potential to be reused into more useful products. Consumption of cooking oil continues to increase in direct proportion to the amount of used cooking oil produced. Therefore, efforts are needed to process used cooking oil waste into something useful, one of which is converting used cooking oil waste into biodiesel.

Biodiesel is an alternative fuel from renewable sources, with a fatty acid composition from vegetable and animal oils [2]. Biodiesel is produced through a transesterification reaction between plant oils or animal fats and alcohol compounds with the presence of a catalyst to increase the conversion and produce glycerol as a by-product.

A compound that when added to a reaction can reduce the activation energy and increase the reaction rate is called a catalyst. During the reaction, the amount of catalyst does not decrease because it does not participate in the reaction [3].

In producing biodiesel, one aspect that plays an important role is the use of catalysts in the triglyceride transesterification reaction. In general, biodiesel is produced using a homogeneous catalyst such as NaOH, however the use of this homogeneous catalyst has disadvantages, namely that it is difficult to separate from the product, it is sensitive to free fatty acids and water contained in the oil, and can easily form soap which can interfere with biodiesel processing compared to heterogeneous phase catalysts. , so the use of heterogeneous catalysts is one solution that can be used to overcome the shortcomings of homogeneous catalysts [4].

In the transesterification process, the use of a catalyst can has a big influence on producing methyl ester. Homogeneous catalysts are less effective because in homogeneous catalysts, the catalyst is difficult to separate from the product and the remaining reactants, whereas in heterogeneous catalysts the separation between the catalyst and the product and the remaining reactants is easily separated. In heterogeneous catalysts, the use of carriers helps the catalyst work more effectively [5].

The added catalyst can be a heterogeneous catalyst (solid) or a homogeneous catalyst. Heterogeneous (solid) catalysts have advantages compared to homogeneous catalysts, namely that they do not mix with the product, so the purification process is easier [6]. One example of a heterogeneous catalyst is low-rank coal (lignite).

According to the Ministry of Energy and Mineral Resources (2021), Indonesia's coal reserves reach 36 billion tons, especially in the Kalimantan region, which is 23.76 billion tons of total coal in Indonesia. However, the quality of Indonesian coal is generally dominated by low-rank coal (lignite) which has a value of around 33.93% of the total available resources.

In general, the biodiesel production process can be made more efficient by using production technology which is now widely researched, namely the use of ultrasonic waves. The use of ultrasonic waves can reduce the energy used for the heating and stirring process [7]. With the help of ultrasonic waves, this is one way that can be done to speed up the reaction time and increase the yield of biodiesel [8].

The production of biodiesel with ultrasonics to see the effect of methanol activation is done by activating the methanol-catalyst mixture in an ultrasonic reactor at various temperature variations inserted into the reactor and the reaction is run for 60 minutes.

The effect of the initial reaction temperature is seen by carrying out the same process with the ratio of reactants. Before being reacted in the ultrasonic reactor, each mixture of methanol and used cooking oil is heated separately at certain temperature variations. After that, it is reacted in the reactor for 60 minutes.

Using ultrasonic waves has a positive effect on increasing methyl ester products. Mixing using ultrasonics is better than using stirring because of the cavitation effect. The reaction rate increases due to the cavitation, thermal, and mechanical effects produced by ultrasonic waves which provide very large energy. The increase in the reaction rate will result in a higher conversion of biodiesel formation and the process will take place faster compared to the process without the use of ultrasonics [9].

The use of ultrasonic waves has also been shown to accelerate the reaction, reduce the amount of catalyst used, and reduce the ratio of oil to alcohol used compared to reactions without the help of ultrasonic waves. This is because ultrasonic waves can increase chemical and physical changes in a medium through the formation and rupture of cavitation bubbles that occur simultaneously and continuously.

The process of producing biodiesel from vegetable oil generally takes a long time, so ultrasonic waves are used so that the mixing process becomes faster, and more perfect and the opportunity for contact between reactant molecules increases intensively. Mixing with ultrasonic waves can increase the mass transfer rate between reacting compounds. This is due to the cavitation, and thermal and mechanical effects produced by ultrasonic waves that provide energy.

2. Research Methods

2.1. Tools and materials used

The tools and materials used in this research include.

2.1.1. Tools used in research

There are several tools used in this research, including 200 mesh sieve, bulb, burette, blender, porcelain cup, glass funnel, separating funnel, crusher, erlenmeyer, furnace, chemical glass, hot plate, digital Balance, Oven, pycnometer, pipette droppers, measuring pipettes, vacuum pump, stainless filter, one set of ultrasonic tools, spatula, statives & clamps, thermometer, vacuum filter flask, Ostwald viscometer.

2.1.2. Materials used in research

In this research, there are 2 materials used, namely as the main material and supporting materials. The main ingredients called raw materials consist of used cooking oil and low-rank coal. The main raw material in the form of used cooking oil was obtained from a restaurant near the Samarinda State Polytechnic and analysed based on the characterization of used cooking oil in the chemical engineering laboratory of the Samarinda State Polytechnic and low-rank lignite coal used as a catalyst was obtained from the East Kutai area of East Kalimantan and analysed using Proximate analysis at PT. Triyasa Pirsa Utama. The supporting materials are Methanol, H_2SO_4, NaOH, and Aquadest obtained from the Basic Chemistry laboratory.

2.2. Research procedures

2.2.1. Production of low-rank coal as a catalyst

The manufacture of low-rank coal as a catalyst includes: Preparing low-rank coal, Carrying out analysis on coal samples with the parameters of water content, ash content, volatile matter, fixed carbon, total sulphur, and heating value, Grind the coal using a crusher and blender, then sift the coal to a size of 200 mesh, Carry out the coal carbonization process at a temperature of 600°C for 2 hours, Cooling coal after the carbonization process in a desiccator, Carry out physical activation at a temperature of 900°C for 2 hours and Cool the coal in a desiccator.

2.2.2. Production of biodiesel

The production of biodiesel includes: Collect used cooking oil ; Analyses used cooking oil, including water content, density, kinematic viscosity, FFA content, and acid number; If the Free Fatty Acid level exceeds 1%, an esterification reaction must be carried out [10]; Separate the esterification results in a separating funnel for 1 hour, then take the bottom layer to be used in the transesterification reaction [11]; Carry out a transesterification reaction by reacting the esterified oil with a catalyst-methanol mixture at a temperature of 60-70°C for 25 minutes, 30 minutes, 35 minutes, and 40 minutes (same treatment as at temperatures of 40, 45, 50, 55 and 60) where 7 grams of catalyst are added with the help of ultrasonic waves to accelerate the rate of the transesterification reaction. The ratio used for oil: ethanol is 1: 3 v/v [12]; Filter the catalyst along with separating the transesterification results in a separating funnel for 12 hours [12]; Take the top layer then heat it on a hot plate, at a temperature of 60-70°C for ± 1 hour to remove the remaining methanol ; Wash the biodiesel using distilled water at a temperature of 70-80°C until the water becomes clear; Put the biodiesel in the oven for ±3 hours at 105 ºC to reduce the water content in the biodiesel and Save the biodiesel results that have been obtained. The resulting biodiesel was stored for characterization testing. A more detailed explanation of the biodiesel production process can be seen in the research flowchart shown in Fig. 1.

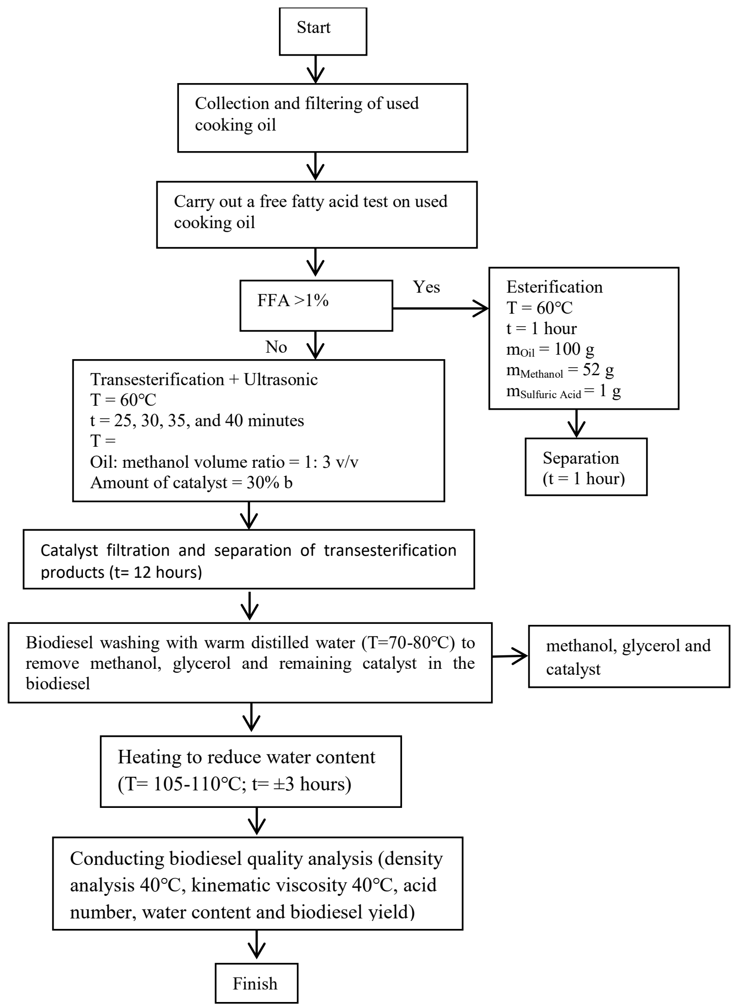

Fig 1. Production of biodiesel

3. Observational Data and Analysis

3.1. Lignite coal data (Catalyst)

Table 1 shows the main raw materials used as catalysts in the biodiesel production process, showing that before the activation process treatment, the total water content, inherent water content, volatile matter, and total sulphur are high, and the ash content, fixed carbon, and calorific value are low.

Table 2 shows that after the thermal activation process, the main raw material as a catalyst in the biodiesel production process, the total water content, inherent water content, volatile matter, and total sulphur are low, while the ash content, fixed carbon, and calorific value are high.

Table 1. Results of low rank coal analysis.

Parameter	Analysis results
Total Moisture, (%)	**37.40**
Inherent Moisture, (%)	**14.02**
Ash Content, (%)	**2.86**
Volatile Matter, (%)	**45.61**
Fixed Carbon, (%)	**32.51**
Total Sulphur, (%)	**0.98**
Calorific Value, (kcal/kg)	**4714**

Table 2. Results of low rank coal analysis (physical activation).

Parameter	Analysis results
Total Moisture, %	15.43
Inherent Moisture, %	3.13
Ash Content, %	38.23
Volatile Matter, %	6.64
Fixed Carbon, %	55.13
Total Sulphur, %	0.42
Calorific Value, (kcal/kg)	6924

In Tables 1 and 2 there is a decrease in water content and substances that are easily degraded. This is because the longer the activation time, the lower the water content and volatile substances, and the lower the volatile substance levels will also be because the amount of water that evaporates is also greater, conversely, if the water content and volatile substances are higher, it can reduce the material's absorption capacity for liquids and gases. Meanwhile, the ash content obtained increased with increasing activity time, this is possibly due to the large ash content caused by the combustion process being carried out in open air so that air contact occurs which results in imperfect carbon formation and greater ash formation.

3.2. Characteristics of used cooking oil and biodiesel production

Table 3 shows the main raw materials in the biodiesel production process showing the results of the characterization analysis of used cooking oil where the density at 40 C is 896.04 kg/m^3, the kinematic viscosity at 40 C is 35.39 mm^2/s while the free fatty acid value is 4.34% and the acid value is 12.57 mgKOH/g which is obtained as a high value, so an esterification process treatment is required because the free fatty acid value is more than 1%.

Table 4 is the result of the analysis of biodiesel characteristics regarding exposure to transesterification time with ultrasonic waves where the density at 40 C, kinematic viscosity at 40 C, water content, acid number, free fatty acids have met the SNI 7182:2015 standard, shown at an exposure time of 35 minutes where the density at 40 oC is 857.2 kg/m^3, the kinematic viscosity at 40 ºC is 3.38 mm^2/s, the water content is 0.032%, the acid number is 0.43 mgKOH/g, the free fatty acid is 0.12% and the yield is 96.55%.

Table 3. Results of analysis of used cooking oil characteristics.

Parameter	Analysis Results
Density, 40 °C, (kg/m^3)	896.04
Kinematic viscosity, 40 °C, (mm^2/s)	35.39
Acid number, (mgKOH/g)	12.57
Free fatty acid content, (%)	4.34
Colour	Abnormal (clear brown)

Table 4. Biodiesel analysis results exposure to transesterification time with ultrasonic waves.

Parameter	Biodiesel Analysis Results Exposure to Transesterification Time with Ultrasonic Waves				SNI 7182:2015
	25 minutes	**30 minutes**	**35 minutes**	**40 minutes**	
Density 40 ºC, (kg/m^3)	861.6	859.3	857.2	856.9	**850-890**
Kinematic Viscosity, 40 ºC, (mm^2/s)	3.63	3.56	3.38	3.31	**2.3-6.0**
Moisture Content, (%)	1.22	1.07	0.032	0.17	**0.05**
Acid Number (mg KOH/g)	1.36	1.45	0.43	2.76	**0.5**
Yield, %	47.44	68.60	96.55	59.90	**-**
Free Fatty Acid Content (%)	**0.67**	**0.53**	**0.12**	**0.73**	**-**

Table 5 is the result of analysis of biodiesel characteristics on exposure to transesterification temperatures with ultrasonic waves where the density at 40 °C, kinematic viscosity at 40 °C, water content, acid number, free fatty acids have met SNI 7182:2015 standards, shown at exposure to a temperature of 50 °C where the density at 40 °C is 857.7 kg/m3, the kinematic viscosity at 40 ºC is 3.57 mm^2/s, the water content is 0.047%, the acid number is 0.37 mgKOH/g, and the yield is 99.21%.

Table 5. Results of biodiesel analysis exposure to transesterification temperature with ultrasonic waves.

Parameter	Results of Biodiesel Analysis of Transesterification Time Variations Using Ultrasonic Waves (35 Minutes)					SNI 7182 :2015
	Temperature 40℃	Temperature 45℃	Temperature 50℃	Temperature 55℃	Temperature 60℃	
Density 40 °C, (kg/m³)	867.1	861.4	857.7	872.6	869.3	**850-890**
Kinematic Viscosity, 40 °C, (mm²/s)	4.94	5.82	3.57	6.47	7.21	**2.3-6.0**
Moisture Content, (%)	0.93	0.41	0.047	0.160	0.62	**0.05**
Acid Number (mg KOH/g)	0.51	0.74	0.37	0.86	0.98	**0.5**
Yield, %	90.22	89.57	99.21	85.73	89.62	-
Colour	**Normal**	**Normal**	**Normal**	**Normal**	**Normal**	**Yellow (Normal)**

4. Results and Discussion

4.1. Effect of transesterification exposure time on biodiesel yield in ultrasonic waves

Based on Fig. 2, shows that increasing time in the transesterification reaction shows an increase in the yield produced, where the highest yield was obtained at 35 minutes, namely 96.55%. However, these results meet the SNI 7182:2015 biodiesel standards. By varying the transesterification time, you can produce an optimal reaction time so you can get a higher yield. However, at 30 and 40 minutes the yield of biodiesel produced decreased due to the formation of soap which occurred through the saponification reaction, where the formation of soap can hinder the conversion of oil into methyl ester [13].

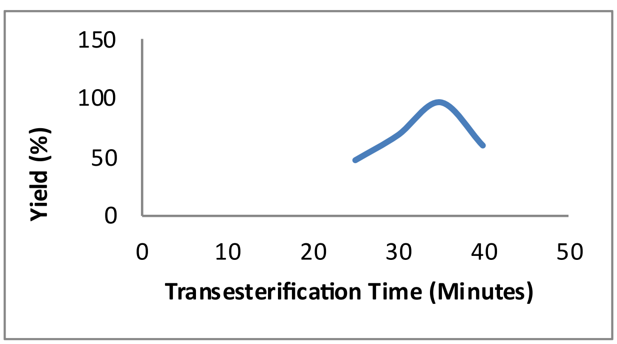

Fig.2. Effect of exposure to transesterification time on biodiesel yield in ultrasonic waves.

4.2. Effect of exposure to transesterification temperature on biodiesel yield in ultrasonic waves

Based on Fig. 3, temperature variations in the transesterification reaction show an increase in the resulting yield, where the highest yield was obtained at a temperature of 50°C, namely 99.21%. According to [14], increasing the temperature in the transesterification reaction will increase the kinetic energy of the reactants and will increase the amount of oil converted into biodiesel. The greater the oil converted into biodiesel, the more biodiesel yield also increases. However, at temperatures of 55 and 60°C, the yield of biodiesel produced decreases which may occur due to the long reaction time, water content, free fatty acid content, soap content and according to [15] the decrease in yield may occur due to the formation of an emulsion. increases viscosity and causes gel formation.

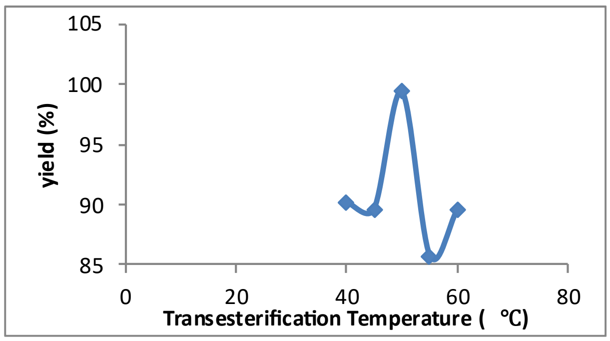

Fig. 3. Effect of transesterification temperature on biodiesel yield under ultrasonic waves.

4.3. Characterization of biodiesel

In the spectrum of Fig. 4, there are sharp absorptions at wavelengths 1234.94, 1743.08, 2921.90, and 3005.47 cm^{-1}. Absorption at 1234.94 cm^{-1} indicates the presence of C-O bonds (1300-1000 cm^{-1}). Meanwhile, the absorption at 1743.08 cm^{-1} indicated the presence of an ester group, namely C=O (1900-1650 cm^{-1}). Then the absorption at 2921.90 and 3005.47 cm^{-1}, showed the presence of C-H bonds (3000-2700 cm^{-1}). The C=O, C-H and C-O bonds in biodiesel prove the presence of methyl ester compounds contained therein. To determine the methyl ester content with an estimate of 99.16%, additional analysis was carried out in detail using the FT-IR ATR-PLS-FAME Quantification method referring to the ASTM D7371 and EN 14078 methods.

Based on GC-MS analysis, Fig. 5, shows that the biodiesel produced has a total of 99.63% methyl ester. In this case, the methyl ester meets SNI 7182:2015, namely a minimum of 96.5%. The results of GC-MS analysis of biodiesel from used cooking oil contain 4 (four) compounds. The content of the methyl ester compound obtained is the fatty acid content found in the basic ingredients of palm cooking oil, such as methyl oleate, methyl palmitate, methyl palmitoleate, and methyl linoleate.

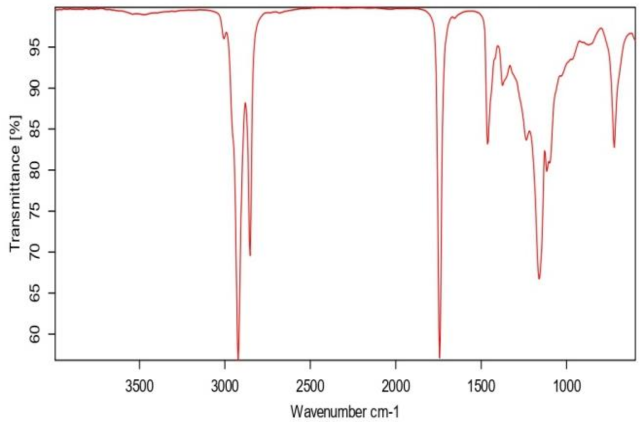

Fig. 4. IR spectrum on Biodiesel with ultrasonic

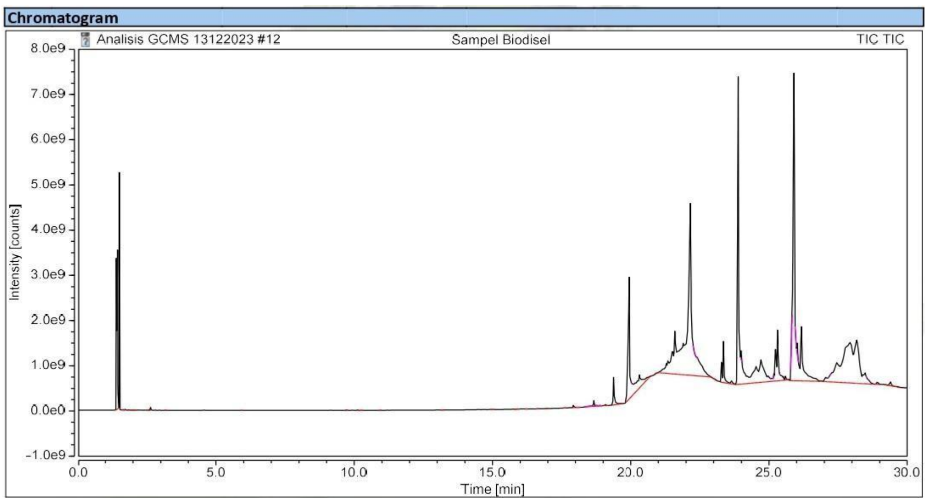

Fig. 5. Methyl ester chromatogram at 50°C.

5. Conclusions

Used cooking oil and methanol (1:3) were transesterified at a temperature of 60°C for varying exposure times of 25 minutes, 30 minutes, 35 minutes, and 40 minutes using 7 grams of low-rank coal catalyst with the help of ultrasonic waves with a frequency of 42 kHz. The best results for exposure to esterification time were 35 C with the highest yield of 97.55%, while for exposure to temperature exposure to temperatures of 40, 45, 50, 55, and 60°C by adding 7 grams of low-rank coal catalyst with the help of ultrasonic waves with a frequency of 42 kHz.

The best results at transesterification temperature exposure were 50 C with the highest yield of 99.21%. In general, the characteristics of the biodiesel produced meet SNI 7182:2015. Based on GC-MS analysis, the resulting biodiesel has a total of 99.63% methyl ester.

Acknowledgements

The author would like to express his deepest gratitude to the Samarinda State Polytechnic Research and Development Center for providing support for this research, and special thanks to Razak, Faculty of Technology and Informatics, Universiti Teknologi Malaysia, UTM Kuala Lumpur, Malaysia who helped promote this article.

Abbreviations	
ASTM	American Standard Testing and Material
FAME	Fatty Acid Metil Ester
FT-IR	Fourier Transform Infra-Red
GC-MS	Gas Chromatography-Mass Spectrometry
SNI	Standard Nasional Indonesia

References

1. Ardhany, S.D.; and Lamsiyah, L. (2018). Tingkat pengetahuan pedagang warung tenda di jalan yos sudarso palangkaraya tentang bahaya penggunaan minyak jelantah bagi kesehatan. *Jurnal Surya Medika* (*JSM*), 3(2), 62-68.
2. Arifin, Z.; Rudiyanto, B.; and Susmiati, Y. (2016). Produksi biodiesel dari minyak jelantah menggunakan katalis heterogen cangkang bekicot (achatina fulica) dengan metode pencucian dry washing. *ROTOR*, 9(2), 100-104.
3. Batubara, D.H. (2018). *Sintesis karbon tersulfonasi dari cangkang kemiri sebagai katalis pada hidrolisis selulosa tanaman alang-alang* (*imperata cylindrica*) *menjadi glukosa*. PhD Thesis, Universitas Sumatera Utara.
4. Devitria, R.; Anita, S.; and Nurhayati. (2018). Sintesis biodiesel dengan katalis heterogen lempung cengar yang diaktivasi dengan naoh : Pengaruh waktu reaksi dan rasio molar minyak: Metanol sintesis biodiesel dengan katalis heterogen lempung cengar. *J. Ind.Che.Acta*, 3(2), 39-44.
5. Ginting, S.O.B.; Daniel, D.; and Hindryawati, N. (2017). Impregnasi natrium hidroksida pada karbon aktif cangkang jengkol sebagai katalis dalam pembuatan biodiesel. *Proceedings of the Prosiding Seminar Nasional Kimia*, Survina Osalia, 143-147.
6. Kibar, M.E.; Hilal, L.; Çapa, B.T.; Bahçıvanlar, B.; and Abdeljelil, B.B. (2023). Assessment of homogeneous and heterogeneous catalysts in transesterification reaction: A mini review. *ChemBioEng Reviews*, 10(4), 412-422.
7. Haryanto, A.; Silviana, U.; Triyono, S.; and Prabawa, S. (2015). Produksi biodiesel dari transesterifikasi minyak jelantah dengan bantuan gelombang mikro: Pengaruh

intensitas daya dan waktu reaksi terhadap rendemen dan karakteristik biodiesel. *Agritech*, 35(2), 234-240.

8. Maisarah, Q.H.; and Hidayati, N. (2019). Transesterifikasi minyak jelantah menjadi biodiesel menggunakan gelombang ultrasonik dan katalis Na_2O/Fly ash. *Proceedings of the Prosiding Seminar Nasional Teknik Kimia* "*Kejuangan*," Indonesia Yogyakarta.
9. Deshmane, V.G.; and Adewuyi, Y.G. (2013). Synthesis and kinetics of biodiesel formation via calcium methoxide base catalyzed transesterification reaction in the absence and presence of ultrasound. *Fuel*, 107, 474-482.
10. Fahlevi, D.R. (2020). *Penggunaan gelombang ultrasonik untuk pembuatan biodiesel* dari *minyak jarak dengan menggunakan katalis KOH*. PhD Thesis, Fakultas Teknik, Universitas Brawijaya.
11. Shen, L.; Pang, S.; Zhong, M.; Sun, Y.; Qayum, A.; Liu, Y.; Rashid, A.; Xu, B.; Liang, Q.; Ma, H.; and Ren, X. (2023). A comprehensive review of ultrasonic assisted extraction (UAE) for bioactive components: Principles, advantages, equipment, and combined technologies. *Ultrasonics Sonochemistry*, 101, 106646.
12. Khoiruummah, D.; Sundari, N.; Zamhari, M.; and Yuliati, S. (2020). Aplikasi katalis berbasis karbon aktif dari kayu akasia (acacia mangium) diimpregnasi basa pada sintesis biodiesel. *Politek. Negeri Sriwij.*, 1(1), 20-28.
13. Kurniasih, E.; and Pardi, P. (2017). Performa katalis basa naoh dan zeolite/naoh pada sintesa biodiesel sebagai sumber energi alternatif. *Proceedings of the Seminar Nasional Sains dan Teknologi* 2017, Fakultas Teknik Universitas Muhammadiyah Jakarta, 1-7.
14. Prihanto, A.; and Irawan, T.B. (2018). Pengaruh temperatur, konsentrasi katalis dan rasio molar metanol-minyak terhadap yield biodisel dari minyak goreng bekas melalui proses netralisasi-transesterifikasi. *Metana*, 13(1), 30-36.
15. Permatasari, A.; Mayangsari, W.; and Gunardi, I. (2013). Pembuatan biodiesel dari minyak nyamplung (Calophyllum Inophyllum L) dengan Reaksi Transesterifikasi Menggunakan Katalis K_2O/H-Za Berbasis Zeolit Alam. *Jurnal Teknik ITS*, 2(2), F290-F295.