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Yield and Characteristics of Biodiesel from Variations in the Mass Ratio of Waste Cooking Oil Mixtures with Different Waste Sources through Homogeneous Catalyzed Esterification and Transesterification Reactions

Rendemen dan Karakteristik Biodiesel dari Variasi Rasio Massa Campuran Limbah Minyak Goreng dengan Perbedaan Sumber Limbah Melalui Reaksi Esterifikasi dan Transesterifikasi Berkatalis Homogen

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ABSTRAK

Bahan bakar fosil sebagai sumber dominan pemenuhan kebutuhan energi merupakan sumber energi tak terbarukan, sehingga cadangannya akan semakin berkurang seiring dengan peningkatan laju konsumsinya. Biodiesel memiliki potensi sebagai bahan bakar menjanjikan yang dapat menggantikan bahan bakar fosil. Biodiesel digunakan sebagai energi terbarukan dan berkelanjutan karena kandungan sulfur yang hampir tidak ada, netral karbon, dan tidak beracun bagi lingkungan. Biodiesel dapat dihasilkan dari asam lemak yang diperoleh dari beberapa bahan baku, seperti minyak nabati, lemak hewan, dan limbah minyak goreng. Namun demikian, pemanfaatan minyak non pangan sebagai bahan baku produksi biodiesel merupakan langkah strategis. Limbah minyak goreng (LMG) sebagai salah satu jenis minyak non pangan memiliki karakteristik bervariasi. Karakteristik dari limbah minyak goreng tersebut akan mempengaruhi kualitas dan jumlah produksi biodiesel. Tujuan penelitian ini adalah untuk menentukan pengaruh komposisi (rasio massa) campuran LMG dari sumber limbah berbeda (ayam goreng, AG; seafood, SF; dan gorengan, GR) sebagai bahan baku pada sintesis biodiesel dengan katalis asam sulfat dan kalium hidroksida. Penelitian diawali dengan pencampuran LMG dengan variasi komposisi LMG (LMG-AG:LMG-SF:LMG-GR) sebagai rasio massa R1(2:3:1), R2(2:2:2), R3(1:2:3), dan R4(3:1:2). Tahap berikutnya adalah pemurnian dan karakterisasi terhadap campuran LMG, esterifikasi dengan katalis asam sulfat, transesterifikasi dengan katalis kalium hidroksida, pemurnian biodiesel, dan karakterisasi biodiesel. Hasil penelitian menunjukkan bahwa Sintesis biodiesel dari campuran LMG dengan komposisi R3 menghasilkan biodiesel dengan rendemen tertinggi, yaitu 92,12%. Sedangan biodiesel dari campuran LMG dengan komposisi R1 memiliki karakteristik paling sesuai dengan standar kualitas biodiesel menurut Keputusan Dirjen EBTKE tahun 2022 berdasarkan parameter-parameter yang diuji.

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ABSTRACT

Fossil fuels, as the dominant source of meeting energy needs, are non-renewable energy sources, so their reserves will decrease as the rate of consumption increases. Biodiesel has the potential to be a promising fuel that can replace fossil fuels. Biodiesel is a renewable and sustainable energy source because it contains almost no sulfur, is carbon neutral, and is non-toxic to the environment. Biodiesel can be produced from fatty acids from several raw materials, such as vegetable oil, animal fat, and waste cooking oil. However, using non-food oil as raw material for biodiesel production is a strategic step. Cooking oil waste, as a type of non-food oil, has varied characteristics. The characteristics of waste cooking oil will affect the quality and quantity of biodiesel production. The research aims to determine the effect of the composition (mass ratio) of WCO mixtures from different waste sources (fried chicken, AG; seafood, SF; and fried foods, GR) as raw materials on the synthesis of biodiesel with sulfuric acid and potassium hydroxide catalysts. The research began with mixing WCO with variations in WCO composition (WCO-AG:WCO-SF:WCO-GR) as mass ratios R1(2:3:1), R2(2:2:2), R3(1:2:3), and R4(3 :1:2). The next stage is purification and characterization of the WCO mixture, esterification with a sulfuric acid catalyst, transesterification with a potassium hydroxide catalyst, biodiesel purification, and biodiesel characterization. The research results showed that the synthesis of biodiesel from a mixture of WCO with R3 composition produced biodiesel with the highest yield, namely 92.12%. Meanwhile, biodiesel from the WCO mixture with composition R1 has the characteristics that best comply with biodiesel quality standards according to the Decree of the Director General of EBTKE in 2022, based on the parameters tested.

1. INTRODUCTION

1.1 Background

Fossil fuels have been reported as the dominant energy source in many countries due to their large industrial, transportation, and agricultural consumption (Monika et al., 2023). According to the Energy Institute (2024), petroleum production in Indonesia, as one of the main types of fossil fuels, tends to decline, from 36.3 million tons in 2020 to 31.1 million tons in 2023. Meanwhile, in 2023, petroleum consumption was higher than its production, namely 1,604 thousand barrels/day or around 78.2 million tons. Fossil fuels, as the dominant source of national energy needs (PT Pertamina, 2023), are non-renewable energy sources, so their reserves will decrease along with the increasing consumption rate. To mitigate climate change, the Indonesian government supports the development of new and renewable energy (NRE), targeting a 19.49% share in the energy mix by 2024 and 23% by 2025 (Ministry of Energy and Mineral Resources, 2024). One form of renewable energy currently receiving attention is biofuel.

Biofuels are the best substitute for fossil fuels because they are renewable, emit fewer harmful gases, and are low-cost compared to conventional fuels (Gaur et al., 2020). Among biofuels, biodiesel is the most promising fuel that can replace conventional fossil fuels. The physical and chemical properties of biodiesel are very similar to those of petroleum-based diesel (Costa et al., 2020). Biodiesel is a renewable and sustainable energy source because it contains almost no sulfur, is carbon neutral, and is non-toxic to the environment. Other advantages for diesel engines include a high flash point, a high cetane number, a high oxygen content, no aromatic compounds. They can reduce greenhouse gas emissions, making it competitive with conventional fossil fuels (Basumatary et al., 2024).

Biodiesel is a fatty acid methyl ester produced from fatty acid esters obtained from various raw materials, such as vegetable oils, animal fats, and waste cooking oil (Monika et al., 2023). In Indonesia, palm oil remains the primary raw material used in biodiesel production. From January to October 2023, the Indonesian Palm Oil Association (GAPKI) reported that of the national palm oil production of 19.03 million tons, palm oil use for biodiesel production was approximately 8.46 million tons. This figure is slightly differs from using palm oil for food, which is 8.6 million tons. Therefore, utilizing non-edible oils as a raw material for biodiesel production is a strategic step.

Waste cooking oil (WCO) can be a good raw material for biodiesel production. Most WCO is disposed of in landfills, drainage systems, or on the ground. Disposal of WCO creates numerous environmental problems. Using WCO as a raw material for biodiesel production would make this process highly economical due to its low cost. Compared with vegetable oil, WCO does not create a contradiction between meeting food needs and fuel, is readily available, and does not cause environmental problems (Adhikesavan et al., 2022).

Triglycerides or free fatty acids contained in vegetable or animal oils, including WCO, are reacted with short-chain alcohols (usually methanol) with the aid of a catalyst in the biodiesel formation reaction. On a commercial production scale, homogeneous catalysts are currently preferred over heterogeneous catalysts due to their more effective catalytic performance (van Gerpen et al., 2004).

WCO has been widely studied as a raw material for biodiesel production using homogeneous catalysts through two reaction stages: esterification and transesterification. However, these studies generally use WCO from a single waste source, as a byproduct of frying various types of food. For example, Andrade et al. (2014), Hamed et al. (2021), and Ulukardesler (2023) utilized WCO from a local general food restaurant, while Saleh & Kulkarni (2014) used WCO from a healthcare clinic kitchen. WCO has unique characteristics compared to fresh oil. The kinematic viscosity, saponification number, flash point, water content, and free fatty acid content of WCO are relatively high, which will affect the quality and quantity of biodiesel production (Alias et al., 2018; Cordero-Ravelo & Schallenberg-Rodriguez, 2018). Various studies have reported that WCO has varying physical and chemical properties, as well as fatty acid composition (Suzihaque et al., 2022). This variability is influenced by differences in cooking oil usage conditions, such as temperature, time, and the type of food being fried (Sanli et al., 2011; Plata et al., 2022). The close relationship between WCO characteristics and the quality and quantity of biodiesel produced in biodiesel synthesis has prompted efforts to map and strengthen the WCO supply chain as a raw material for biodiesel production. To further ensure the uniformity of WCO characteristics, WCO can be collected from restaurants serving specific food types, such as seafood and fried chicken restaurants. Therefore, to reduce dependence on raw material supply from restaurants with specific types of food, studying the effect of WCO composition based on the variability of waste sources (restaurants) on the quality and quantity of biodiesel produced is a strategic effort in designing a sustainable WCO-based biodiesel production process system.

1.2 Research Objectives

This study aimed to determine the effect of the composition (in mass ratio) between types of waste cooking oil on the yield and characteristics of biodiesel in biodiesel synthesis with a homogeneous catalyst. The quality of biodiesel due to variations in the types of waste cooking oil was determined by comparing the characteristics of the biodiesel from the synthesis results with the biodiesel quality standards according to the Decree of the Director General of New, Renewable Energy, and Energy Conservation in 2022.

2. METHODOLOGY

2.1 Tools and Materials

The research was conducted using equipment including: a 1000 mL Pyrex reactor flask for biodiesel synthesis, a hot plate magnetic stirrer (IKA C-MAG HS 4), a 500 mL Pyrex boiling flask, a heating menthol (EM0500/CE), a Buchner filter, a 10 mL Pyrex pycnometer, an Ostwald viscometer (Pyrex), a Fourier Transform Infrared (FT-IR) spectrometer (Perkin Elmer), a thermometer (AllanFrance), 60-mesh filter paper, and a thermostat.

The raw materials for biodiesel synthesis were waste cooking oil (WCO) from fried chicken (WCO-AG); fried tofu, tempeh, bakwan, and pastel (WCO-GR); and seafood such as squid, shrimp, crab, and sea fish (WCO-SF) from the Jatinangor area. WCO-SF was randomly collected from vendors, so the characteristics of WEL-SF as a raw material for biodiesel synthesis were not controlled factors. At the same time, the chemicals used consist of 97% sulfuric acid (Smart Lab Indonesia), potassium hydroxide p.a. (Merck), 98% methanol (Merck), glacial acetic acid (technical, Smart Lab Indonesia), distilled water, oxalic acid p.a. (Smart Lab Indonesia), acetone, 95% ethanol (Smart Lab Indonesia), phenolphthalein indicator (Merck), 37% hydrochloric acid (Merck), starch indicator (Smart Lab Indonesia), potassium iodide p.a. (Merck), chloroform p.a. (Merck), sodium thiosulfate p.a. (Merck), potassium iodate p.a. (Merck), acetic acid p.a. (Merck), and iodine monochloride p.a. (Merck).

2.2 Research Procedure

This research was conducted in the Physical Chemistry Laboratory, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Padjadjaran University, from January to July 2024. The study involved a laboratory experiment consisting of seven treatment stages. In the first stage, WCO was mixed with four variations in mass ratios: WCO-AG, WCO-SF, and WCO-GR (R = WCO-AG : WCO-SF : WCO-GR) at ratios R1 (1:2:3), R2 (2:2:2), R3 (3:2:1), and R4 (2:3:1). The WCO mixtures with these four variations in mass ratios were then characterized to determine their initial characteristics. The next stage was purification of the WCO mixture using sedimentation, filtration, evaporation, and adsorption methods using activated charcoal as an adsorbent.

After purification, the WCO mixture was converted into biodiesel through two reaction stages: esterification with a sulfuric acid catalyst and transesterification with a potassium hydroxide catalyst. The results of biodiesel synthesis from the four variations of the WCO mixture mass ratio were then purified, and the yield and quality were determined.

2.2.1. Purification and Characterization of WCO Mixtures

The purification of the WCO mixture with four variations in mass ratio began with separating suspended solid impurities by sedimentation. Sedimentation was carried out for 24 hours at room temperature in a separating funnel, allowing the suspended particulate impurities to separate at the bottom of the separating funnel by gravity, utilizing the density difference between the suspended particulates and the oil. The supernatant WCO mixture (the top layer of the WCO mixture at the end of sedimentation) was then filtered using a Buchner filter with 60-mesh filter paper. Filtration was performed to separate the remaining solid impurities in the form of dispersed particulates that could not be separated based on the density difference. The WCO mixture, as the filtrate from the filtering results, was then adsorbed using activated charcoal for 1 hour at 70°C with a ratio of activated charcoal to WCO of 1:20 (w/v) (Salomo et al., 2016). The water content of the WCO mixture was then reduced to no more than 1% by heating at 105°C for 2.5 hours (van Gerpen et al., 2004).

The purified WCO mixture was analyzed to determine its characteristics based on procedures according to SNI 7182:2015. The analysis of the WCO mixtures at each mass ratio variation included density, viscosity, acid value, peroxide value, and water content. The same analytical parameters were also determined for the WCO mixtures before purification.

2.2.2. Biodiesel Synthesis and Purification

The biodiesel synthesis from the WCO mixture for each variation of mass ratio (R1, R2, and R3) that has been purified and characterized begins with the esterification stage. At this stage, a 150 mL sample of the WCO mixture is reacted in a three-neck flask reactor. Esterification is carried out for 2 hours at an oil/methanol mole ratio of 1:9, sulfuric acid content as a catalyst of 1% by weight of oil, a temperature of 60°C, and a stirring speed of 600 rpm (Elma et al., 2018). The esterified mixture is then distilled to separate the residual methanol. Next, the residual catalyst is separated from the oil phase by washing with hot distilled water (40°C) in a separating funnel. The oil phase (consisting of methyl ester/biodiesel and triglycerides) is then purified from the possible presence of wash water as an emulsion by heating with stirring at a temperature of 105°C for 2.5 hours.

The oil phase from the esterification stage is further reacted in the transesterification stage based on the procedure according to Refaat et al. (2008). This stage begins with preparing a potassium methoxide solution as a catalyst by dissolving 1.5% potassium hydroxide by weight of the oil phase into methanol. The amount of methanol required is calculated based on the mole ratio of the oil phase to methanol, which is set at 1:9. The oil phase is then reacted with the potassium methoxide solution at 60°C for 2.5 hours in a three-neck flask reactor device. The transesterification mixture is put into a separating funnel to carry out the biodiesel purification stage from impurities in the form of glycerol (by sedimentation), residual potassium hydroxide catalyst (by washing with distilled water, and decantation), and residual wash water (by heating at 105°C for 2.5 hours). The biodiesel from the transesterification stage is then weighed for yield calculation based on Equation (2) and then characterized to determine its quality.

2.2.3. Biodiesel Characterization

Biodiesel from each variation of mass ratio in the WCO mixture, after purification, was characterized for the parameters of density, viscosity, water content, acid number, iodine number, and peroxide number based on the method according to SNI 7182-2015 (SNI is a technical standard established to determine the quality of commercial products in Indonesia). In the characterization of biodiesel due to the transesterification stage, the cetane number was also determined, in addition to these parameters. The cetane number was determined by referring to Equation (1) as a function of saponification and iodine numbers (Azam et al., 2005). To confirm that the molecular structure of the biodiesel had been formed, functional group identification was carried out using FTIR (Fourier Transform Infra Red) spectroscopy.

$$CN = 46.3 + \frac{5458}{SN} - 0.255IN \text{......................(1)}$$

where,
CN = cetane number
SN = saponification number (mg KOH/g)
IN = iodine number (g I_2/100 g)

Equation (2) was used to calculate the biodiesel yield from each variation of mass ratio in the WCO mixture (Sahar et al., 2018).

$$\text{Yield of biodiesel} = \frac{\text{Weight of biodiesel}}{\text{Weight of WCO}} \times 100\% \text{...............(2)}$$

3. RESULTS AND DISCUSSION

3.1. Characteristics of Waste Cooking Oil Mixture Before and After Purification

The purification stage for WCO reduces levels of impurities, particularly suspended and dispersed solids, water, free fatty acids, and peroxide compounds. These impurities represent the impact of various factors in the frying process, such as frying time, frying temperature, and the characteristics of the fried food (Sanli et al., 2011).

This study used three types of WCO: WCO from chicken (WCO-AG), fried food (WCO-GR), and seafood (WCO-SF). Regarding physical appearance, the three types of WCO are light to dark brown and have a relatively strong odor, especially WCO-SF, as shown in Figure 1. Meanwhile, the characteristics of WCO mixture samples from each variation of mass ratio (R1, R2, R3, and R4) before and after purification are shown in Table 1. Cooking oil will undergo hydrolysis and oxidation reactions, producing free fatty acids and volatile compounds during use, especially when used for frying several times, so that it can change the color of the oil and its aroma (Nayak et al., 2016; Tsoutsos et al., 2016).

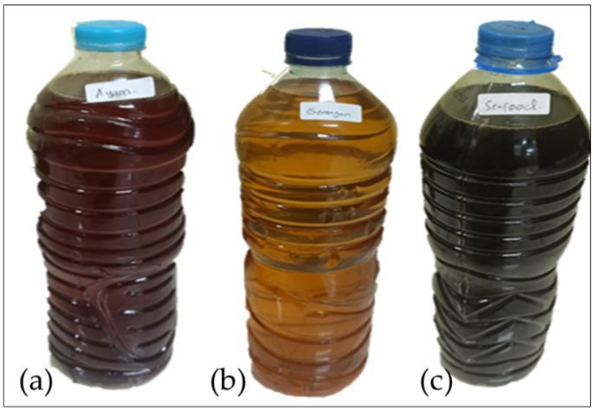

Figure 1. Color appearance of four types of WCO: (a) WCO-AG, (b) WCO-GR, and (c) WCO-SF

The WCO mixtures before purification in this study had densities between 899.6–906.1 kg/m^3. The density of the WCO R2(2:2:2) mixture showed the lowest value, while the WCO R4(2:3:1) mixture had the highest density. In WCO, the density value is more related to impurities in the form of solids. One of these solid impurities is the formation of polymer material due to the polymerization reaction during the frying process. There is a consistent trend that as the frying time increases, the amount of polymer material formed increases (Adhikesavan et al., 2022). The WCO R4 mixture, which has the highest mass proportion of WCO-SF, had the highest density before the purification stage. Because the density value of a mixture is a proportional contribution of the densities of its constituent components, it is estimated that WCO-SF has a higher density than other types of WCO.

Oil viscosity is related to the acid number. A higher acid number generally increases oil viscosity (Alias et al., 2018). This trend aligns with the results of this study, where before purification, the WCO R2 mixture with the highest viscosity (25.45 mm^2 s^{-1}) had the highest acid number, at 13.60 mg KOH/g.

Table 1. Characteristics of WCO mixtures at variations of mass ratios R1, R2, R3, and R4 between before and after purification

Parameters	Campuran WCO							
	R1		R2		R3		R4	
	Before	After	Before	After	Before	After	Before	After
Density at 40°C (kg m^{-3})	901.1	901.8	899.6	899.7	904.3	895.3	906.1	901.4
Viscosity at 40°C (mm^2 s^{-1})	15.54	13.27	25.45	12.01	13.83	12.38	14.53	12.58
Acid number (mg KOH/g)	9.36	0.93	13.60	0.95	12.93	1.02	11.59	0.54
Sediment content (%)	0.56	0.14	0.42	0.04	0.14	0.04	0.08	0.08
Moisture content (%)	0.60	0.08	0.49	0.15	0.14	0.05	0.20	0.09
Saponification number (mg KOH/g)	259.5	206.7	276.5	217.8	283.0	204.1	271.7	177.8

Where: R = WCO-AG:WCO-SF:WCO-GR, R1 = 1:2:3, R2 = 2:2:2, R3 = 3:2:1, R4 = 2:3:1

After the purification stage of the WCO mixture, based on the data in Table 1, the values of all test parameters of the WCO mixture for all variations in mass ratio decreased. This indicates that the purification stage of the WCO mixture is relatively effective in separating various types of impurities present in the WCO mixture. The results of other studies align with the results of this study, considering the variety of WCO types. Each type of WCO has varying characteristics, so its impact on the characteristics of mixtures between WCO at various compositions will also vary, depending on the type of fried food, temperature, oil source, and frying time (Plata et al., 2022). Regarding the acid number parameter, for example, Farooq et al. (2015) reported that the WCO acid number of fried crispy chicken was 35.4 mg KOH/g, while the WCO acid number of fried mixed food ingredients was 28.5 mg KOH/g (Aworanti et al., 2019) and 36.0 mg KOH/g (Al-Saadi et al., 2020).

3.2. Biodiesel Yield from Esterification and Transesterification Stages

After purification of the WCO mixture, each variation of the mass ratio of the WCO mixture was converted into biodiesel through two reaction stages, namely esterification with a sulfuric acid catalyst, then a transesterification reaction with a potassium hydroxide catalyst. The physical appearance of the transesterification results of various WCO mixtures after the complete purification stage is shown in Figure 2. At the same time, the biodiesel yield of each variation of the mass ratio of the WCO mixture after the purification stage is shown in Figure 3.

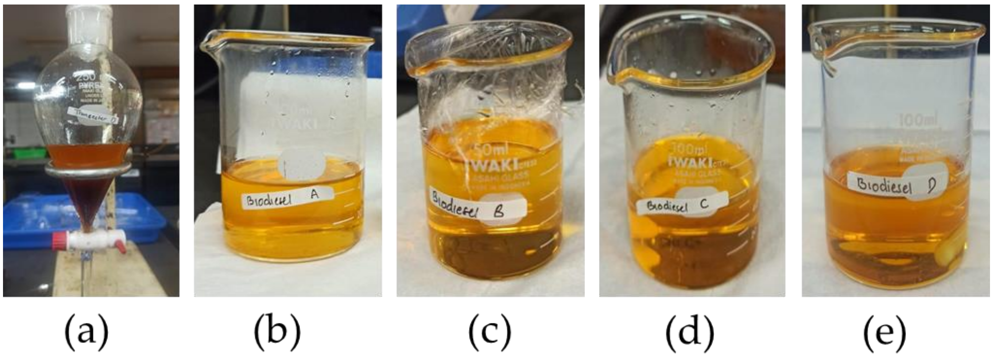

Figure 2. Physical appearance of biodiesel from transesterification: (a) crude biodiesel, (b) R1 biodiesel, (c) R2 biodiesel, (d) R3 biodiesel, and (e) R4 biodiesel

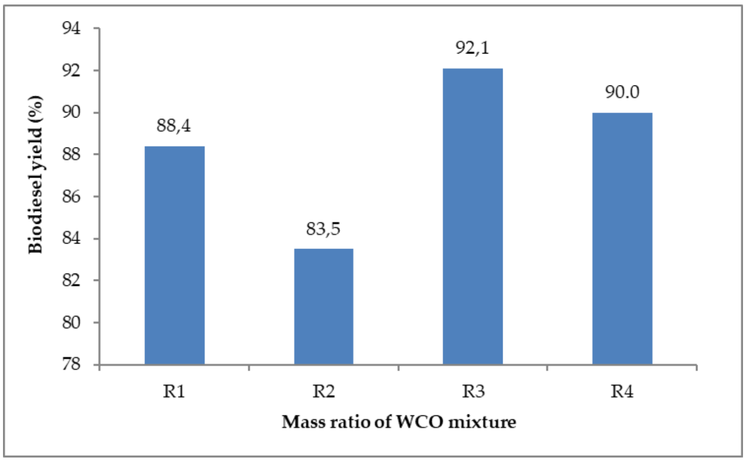

Figure 3. Biodiesel yield from each mass ratio of WCO mixture

The data in Figure 3 shows that the WCO R3 mixture (3:2:1) produced the highest biodiesel yield, at 92.1%. The lowest biodiesel yield (83.5%) was obtained when using the WCO R2 mixture (2:2:2). Meanwhile, the biodiesel yields from the WCO R1 (1:2:3) and R4 (2:3:1) mixtures were 88.4 and 90.0, respectively. The difference in biodiesel yield from various WCO mixtures is influenced by the characteristics of each variation in the WCO mixture mass ratio after the purification stage. The highest biodiesel yield from using the WCO R3 mixture is estimated because this mixture has the lowest water content compared to other variations in mass ratios. This results in more effective biodiesel synthesis during the esterification stage. The higher water content in vegetable oil will significantly reduce the conversion rate of free fatty acids into biodiesel during the esterification stage (Haryono et al., 2023). Furthermore, the WCO R3 blend had the highest acid number after purification, representing the oil's free fatty acid content. Therefore, combining the lowest water content and the highest acid number of the WCO R3 blend resulted in a higher biodiesel yield during the esterification stage.

Plata et al. (2022) stated that different WCO sources have different usage conditions, such as heating temperature and duration, continuous heating usage period, and the type of food being fried. The different characteristics of each WCO source will contribute to the characteristics of the mixture between the WCOs, thus affecting the biodiesel yield (Alias et al., 2018). Biodiesel synthesis through a two-stage process (esterification and transesterification) is generally more advantageous using WCO with a high free fatty acid content (Cordero-Ravelo & Schallenberg-Rodriguez, 2018).

Table 2. Comparison of biodiesel yield from WCO under applied synthesis conditions

Types or Sources of WCO [a)]	Synthesis Conditions [b)]	Yield (%)	Referensi
Public restaurant	3:1 (v/v), 0,4% KOH, 60°C, 3 h	94.4	Hamed et al. (2021)
Public clinic kitchen	4:1 (v/v), 0.4% KOH, 60°C, 3 h	94.4	Saleh & Kulkarni (2014)
Public restaurant	1:15 (mol/mol), 5.0% KOH, 65°C, 2 h	95.0	Ulukardesler (2023)
Public restaurant	1:9 (mol/mol), 0.7% KOH, 50°C, 1 h	94.8	Andrade et al. (2014)
Chicken fat	1:9 (mol/mol), 0.5% KOH, 35°C, 1 h	94.0	Andrade et al. (2014)
WCO mix of fried chicken, seafood, and fried foods (R1)	1:9 (mol/mol), 1.5% KOH, 60°C, 2.5 h	88.4	This study

[a)] Public = various foodstuffs, R1(1:2:3), [b)] types: oil/methanol ratio, catalyst content, reaction temperature, reaction time

Other researchers have reported varying results regarding biodiesel yield due to variations in WCO type. However, it should be reiterated that previous researchers typically based their research procedures on using WCO from restaurants with various types of fried foods, or WCO from a specific type of vegetable oil, without specifying the type of fried food. Table 2 compare research results on the relationship between WCO type and biodiesel yield produced through esterification and transesterification with a homogeneous catalyst. Based on the data in Table 2, there is variability in biodiesel yield. These differences in yield values are principally due to the characteristics of the raw materials and the synthesis conditions applied. However, in addition to yield parameters, the quality parameters of the resulting biodiesel should also be an important reference in determining optimal synthesis conditions, such as density, viscosity, cetane number, and other quality parameters as stipulated in the Decree of the Director General of New, Renewable Energy and Energy Conservation (EBTKE = Energi Baru-Terbarukan dan Konversi Energi) in 2022.

3.3. Biodiesel Characteristics from Variations in WCO Mixture Mass Ratio

Biodiesel from each WCO blend mass ratio variation (R1, R2, R3, and R4), was then characterized for several quality parameters after being purified to remove impurities, specifically glycerol, residual methanol, catalyst, and water. The biodiesel quality parameters tested included density and viscosity at a test temperature of 40°C, acid value, water content, iodine value, and cetane number. The characteristics based on these biodiesel quality parameters were then compared to the national standards stipulated in the 2022 Decree of the Director General of New, Renewable Energy and Energy Conservation (EBTKE). The biodiesel characteristics from this study and their comparison with these biodiesel quality standards are shown in Table 3.

Table 3. Characteristics of biodiesel results from research and comparison with quality standards

Parameters	Biodiesel				SK EBTKE 2022
	R1	R2	R3	R4	
Density at 40 °C (kg m^{-3})	883	871	856	860	850-890
Viscosity at 40 °C (mm^2 s^{-1})	5.8	5.2	3.0	3.3	2.3-6.0
Acid number (mg KOH/g)	0.30	0.52	0.44	0.50	Max. 0.4
Moisture content (ppm)	383	424	343	419	Max. 340
Iodine number (g-I_2/100 g)	6.84	7.62	17.49	3.26	Max. 115
Cetana number	71	69	69	76	Min. 51

Based on the data in Table 3, biodiesel from all WCO blend mass ratio variations met the biodiesel quality standards stipulated in the 2022 Decree of the Director General of New, Renewable Energy and Energy Conservation (EBTKE), except for acid value and water content. Biodiesel from the WCO blend at the R1 mass ratio variation had the best quality. Only the water content parameter did not meet the standard. The variability in biodiesel characteristics from each variation in the WCO mixture mass ratio is influenced by the variability in the characteristics of the oil as the raw material, so this will affect the performance (effectiveness) in the synthesis stage, both the esterification and transesterification stages (Alias et al., 2018).

The WCO R1 mixture produces the best quality biodiesel and provides a relatively high yield, 88.4%. Therefore, the use of a WCO mixture with a mass ratio of R1 (1:2:3) in the two-stage biodiesel synthesis with a homogeneous catalyst (sulfuric acid in the esterification stage and potassium hydroxide in the transesterification stage) is determined as the optimum WCO mixture condition.

3.4. Characteristics of Biodiesel Functional Groups

Biodiesel from a WCO blend at the optimum mass ratio (R1) was characterized by functional groups using FTIR spectroscopy to confirm the formation of its molecular structure. The FTIR spectrum pattern resulting from this functional group characterization is shown in Figure 4.

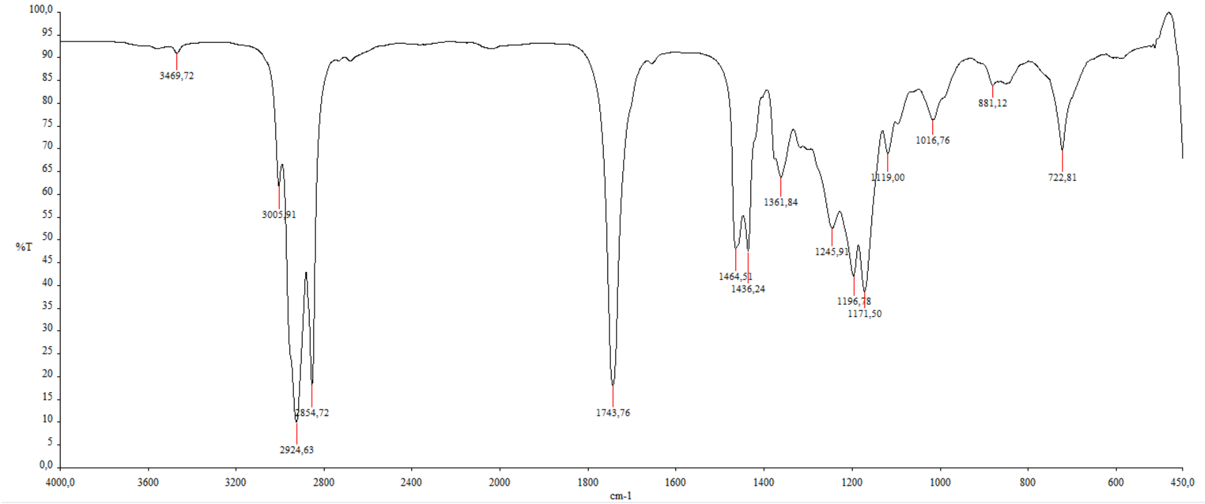

Figure 4. FTIR spectrum of biodiesel from WCO mixture at mass ratio R1

Infrared energy absorption at 3469.72 cm^{-1} represents the hydroxyl group (OH). Infrared energy absorption at 1743.76 cm^{-1} represents the C=O stretching vibration, and at 1245.91, 1196.78, and 1171.50 cm^{-1} represent the C-O bending vibration, indicating the presence of ester groups (Shalaby & El-Gendy, 2012; Tariq et al., 2011) in the biodiesel. Infrared energy absorption at wave number 3005.91 cm^{-1} represents the stretching vibration of C=C-H (sp2) or double cis vibration in biodiesel, generally found in carbon chain compounds of biodiesel. Wave numbers 2924.63 cm^{-1} and 2854.72 cm^{-1} represent the bending vibration of CH_2 (Ali et al., 2018), and 1464.51 cm^{-1} represents the vibration absorption of C-H. The methyl and ester groups from the characterization results confirm that biodiesel has been successfully synthesized from the reaction between a mixture of WCO at an optimum mass ratio (R1) with methanol, assisted by sulfuric acid catalysts in the esterification stage and potassium hydroxide in the transesterification stage.

4. CONCLUSION

The composition (in mass ratio) between types of waste cooking oil from different waste sources affects biodiesel yield in biodiesel synthesis using a homogeneous catalyst. Mixtures of waste cooking oil with the lowest water content and the highest free fatty acids tend to produce biodiesel with a higher yield.

The composition of the waste cooking oil mixture also influences biodiesel quality characteristics. A mixture of waste cooking oil with a mass ratio of 1:2:3 (R1) between waste cooking oil from fried chicken, seafood, and fried foods produced biodiesel with the highest quality compared to the biodiesel quality standards set by the Decree of the Director General of New, Renewable Energy and Energy Conservation (EBTKE) in 2022 for the tested quality parameters. Meanwhile, functional group characterization using FTIR spectroscopy successfully confirmed the formation of biodiesel. The results of this study provide technical information related to managing raw material supply in the form of waste cooking oil from specialty food restaurants, which can be used to develop a more sustainable biodiesel production process system on an industrial scale.

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