**Journal of Sustainable Agriculture and Biosystems Engineering**
Journal homepage: https://talenta.usu.ac.id/jsabe

# Study on the Use of Perforated LPD (Low Pressure Drop) Type Static Mixer in the Catalytic Biodiesel Production Process

Nopita Aisyah Tobing*[1], Sulastri Panggabean[1]
[1]*Universitas Sumatera Utara, Faculty of Agriculture, Department of Agricultural and Biosystems Engineering, Prof. A. Sofyan No.3, 20155, Indonesia,*
*Corresponding Author: nopitaaisyah2001@gmail.com

**ARTICLE INFO**

**Article history:**
Received 04 November 2024
Revised 09 July 2025
Accepted 25 July 2025

E-ISSN: 3026-4065

**How to cite:**
Tobing N A, Panggabean S, "Study on the Use of Perforated LPD (Low Pressure Drop) Type Static Mixer in the Catalytic Biodiesel Production Process", Journal of Sustainable Agriculture and Biosystem Engineering, Vol. 03, No. 02, 2025.

## ABSTRACT

The development of biodiesel as an alternative energy source is crucial in addressing the global fossil fuel crisis, particularly for diesel fuel in Indonesia. This study evaluates the effectiveness of a perforated Low Pressure Drop (LPD) type static mixer in catalytic biodiesel production using reduced concentrations of KOH catalyst (0.5%, 0.4%, and 0.3%). The innovation lies in the application of a perforated LPD-type mixer, which had previously only been studied through simulations. By implementing this mixer experimentally, the study demonstrates improved biodiesel quality parameters—such as lower acid number, lower viscosity, reduced total glycerol, and enhanced methyl ester content. The highest methyl ester yield (99.65%) was obtained at 0.5% catalyst concentration, yet the 0.4% concentration achieved comparable results with greater cost and environmental efficiency. These findings confirm that the use of a perforated LPD static mixer not only enhances the mixing process but also reduces the need for higher catalyst dosage, presenting a practical advancement in biodiesel production technology.

**Keyword:** Biodiesel, Static mixer, Perforated LPD (Low Pressure Drop)

**DOI: 10.32734/jsabe.v3i02.18762**

## 1. Introduction

In Indonesia, the need for energy from fossil fuels is increasing rapidly in various sectors, so the development of sustainable alternative energy sources is needed. One such alternative is biodiesel, which is produced from vegetable or animal oils, with CPO (Crude Palm Oil) as the main raw material. Indonesia, as the largest CPO producer, is taking advantage of the B35 biodiesel program to develop the use of CPO as biodiesel [1].

Biodiesel is made through a transesterification reaction, which is suitable for use in diesel engines and has the potential to replace diesel due to its similar characteristics. Biodiesel is renewable and sulfur-free, supports environmental sustainability by reducing acid rain damage, and is easy to process and degrade. The biodiesel production process can be done by two methods: noncatalytic and catalytic. Noncatalytic methods are simple and do not require catalysts, but require special conditions and high costs to achieve activation energy [2]. In contrast, catalytic methods use catalysts (such as NaOH or KOH) to accelerate the reaction between triglycerides and methanol or ethanol, although they require complex purification.

The catalytic biodiesel production process requires a catalyst to reduce the activation energy and accelerate the reaction. Catalysts create alternative pathways with minimum activation energy and do not change the concentration of the reaction products. Biodiesel can be produced using acid catalysts for oils with high FFA content (esterification) and base catalysts for oils with low FFA content (transesterification) [3].

The use of catalysts in biodiesel production has several problems, including a long purification process, the potential for saponification, and high catalyst prices. Therefore, the production process can be improved by maximizing the mixing of triglycerides and methanol through stirring. However, stirring requires a lot of energy due to the immiscible nature of methanol and oil. One solution is the use of a static mixer reactor (SMR) that allows for more effective mixing without moving parts, reduces catalyst requirements, and speeds up the reaction process. LPD-type static mixers, in particular, provide efficient mixing with minimal pressure drop.

LPD-type static mixers (Low Pressure Drop static mixers) are mixing devices that operate without moving parts and are designed to enhance mixing efficiency while minimizing energy loss due to pressure drop. These mixers function by continuously dividing, rotating, and recombining fluid flow through internal elements, creating turbulence that improves homogeneity of mixtures. In biodiesel production, they are used to facilitate the mixing of immiscible liquids such as oil and methanol, which enhances the transesterification reaction and reduces the need for mechanical stirring and high catalyst concentrations. The perforated variant of the LPD-type static mixer increases flow disturbances and improves contact between reactants, thereby boosting the yield and quality of biodiesel. Computational simulations and experimental results have demonstrated that perforated LPD mixers can increase methyl ester content more effectively than non-perforated designs [4]. This technology is recognized and commonly used in chemical and process engineering applications.

In addition to the unperforated LPD type static mixer, the perforated LPD type static mixer also has the potential for biodiesel production. Using CFD simulations, the use of a perforated LPD type static mixer can increase the FAME value obtained. In addition, this type will also provide a fairly good flow distribution [4]. Since the previous research was still carried out in the form of simulations, in this study, catalytic biodiesel production experiments were carried out with the use of smaller amounts of catalysts, namely 0.5%, 0.4% and 0.3% KOH catalysts with the aim of examining the quality of biodiesel produced.

## 2. Materials and Methods

The materials used in this study were palm oil as the vegetable oil source. The vegetable oil used in this study was sourced from crude palm oil (CPO), which was selected due to its high availability and widespread use as a biodiesel feedstock in Indonesia. Methanol as the alcohol reactant, potassium hydroxide pro analysis (KOH PA) as the catalyst, and distilled water. The KOH catalyst was applied in three different concentrations: 0.3%, 0.4%, and 0.5% w/w, calculated based on the weight of the palm oil. This means that the amount of KOH added to each treatment was 0.3%, 0.4%, or 0.5% of the total weight of the oil. The purpose of this variation was to evaluate the effect of catalyst concentration on the quality of biodiesel produced.

The main equipment used in this research was a Static Mixer Reactor (SMR), specifically designed with perforated LPD (Low Pressure Drop) elements to enhance the mixing efficiency of immiscible fluids such as oil and methanol. The production process was carried out at a constant reaction temperature of 60°C using a fixed molar ratio of oil to methanol of 1:6. The reactor operated continuously with nine perforated LPD-type units, each measuring 60 cm in length.

After the transesterification reaction, the biodiesel was separated from glycerol by precipitation. The biodiesel layer was then washed using distilled water until the pH reached a neutral level, and the final stage was evaporation at 100–105°C for one hour to remove any residual methanol and water. The biodiesel samples were subsequently analyzed in the laboratory.

Figure 1. Static Mixer Reactor (SMR)

The parameters in this study are; (1) Acid Number; The amount of KOH (mg) to neutralize free acid in 1 gram of sample (AOCS Cd 3d-63 method). (2) Saponification Number; KOH (mg) to saponify 1 gram of biodiesel (AOCS Cd 3-25 method). (3) Total Glycerol; The amount of free and bound glycerol in the sample (AOCS method Ca 14-56). (4) Viscosity; Determined with an Ostwald viscosimeter. (5) Methyl Ester Content; Calculated by the formula :

$$\text{Ester content (\%mass)} = \frac{100(As - Aa - 4{,}57Gttl)}{As} \tag{1}$$

Description:
$AS$ = saponification number (mg KOH/g)
$Aa$ = acid number (mg KOH/g)
$Gttl$ = total glycerol content in biodiesel (%-mass).
The percentage of methyl ester must be >96.50% w/w (SNI 2006).

The experimental design used was a non-factorial Completely Randomized Design (CRD) with three treatments (K1 = 0.3%, K2 = 0.4%, and K3 = 0.5%) and six replications for each treatment. The data were statistically analyzed using Analysis of Variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) when significant differences were found.

## 3. Result and Discussion

### *3.1* Catalytic Biodiesel Production Process with Static Mixing Reactor

This study produced biodiesel with KOH catalyst reduced to 0.5%, 0.4%, and 0.3% by weight of oil, using an oil-methanol ratio of 1:6 at 60°C. This study used a perforated LPD-type static mixing reactor with turbulent flow to effectively mix the materials. This reactor works statically without moving parts, resulting in a homogeneous and accurate mixture in the absence of entrained air [4]. The system mixes the fluid by dividing, inverting, and recombining the materials so that they are evenly mixed. The reactor operates continuously with 9 perforated LPD-type units each measuring 60 cm, ensuring even distribution of materials.

Figure 2. Crude biodiesel sample

The transesterification process produces crude biodiesel that needs to be precipitated to separate glycerol and residual catalyst (Fig.2). After precipitation, the biodiesel is washed using distilled water until the pH stabilizes to remove glycerol and residual chemicals. The final step is evaporation at 100-105°C for one hour to remove water and residual methanol. The clean biodiesel is then tested in the laboratory to ensure quality standards.

### *3.2* Acid Number

Determination of the acid number in biodiesel is important to measure the acid content that can affect engine performance, such as causing corrosion and swelling of diesel injectors and ash formation that damages fuel pumps and filters. Low acid number values indicate high conversion of fatty acids to methyl esters, signaling successful biodiesel production [5]. Acid number measurement is done by adding alcohol to dissolve fatty acids [6] and the test results at 60°C with 0.3%, 0.4%, and 0.5% KOH catalysts are presented in Figure 3.

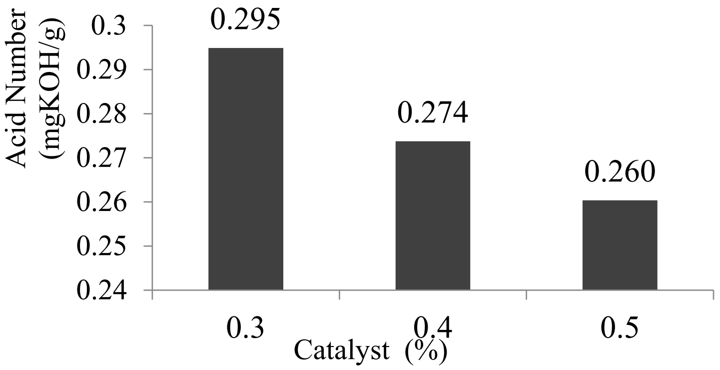

Figure 3. Graph of average acid number values

The results showed that the acid number of biodiesel decreased as the catalyst concentration increased. The 0.3% catalyst concentration produced the highest acid number (0.29488 mgKOH/g), while the 0.5% concentration produced the lowest acid number (0.26035 mgKOH/g). Although these values are lower than previous studies [7], they still meet the biodiesel standard (maximum 0.4 mgKOH/g). The decrease in acid number indicates an effective transesterification process and good catalytic activity, although the variation in catalyst concentration did not show a significant effect according to CRD analysis, so DMRT analysis was not required.

*3.3* Saponification Rate

The saponification number indicates the amount of feedstock lost during methyl ester production, with high values indicating low fatty acid levels and good biodiesel quality [8]. Conversely, a low saponification number indicates high fatty acids, which can reduce biodiesel quality. The results of the saponification number in this study are presented in Figure 4.

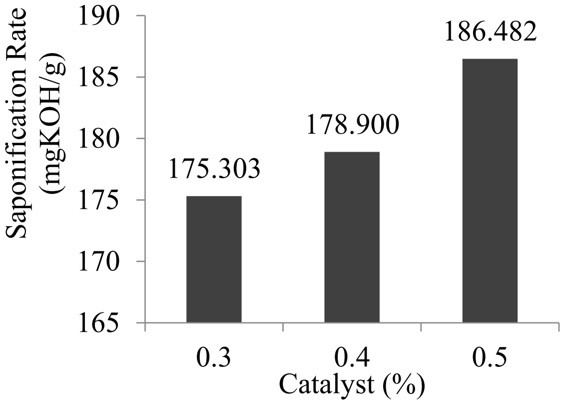

Figure 4. Graph of average value of saponification number

The study showed that increasing the catalyst concentration (0.3%, 0.4%, and 0.5% w/w oil) increased the saponification number, from 175.30 mgKOH/g at 0.3% concentration to 186.48 mgKOH/g at 0.5%. This value is higher than the saponification number of LPD without holes (158.9 mgKOH/g) and is related to the acid number; the higher the acid number, the lower the saponification number. According [9] the increase in saponification rate is influenced by the amount of catalyst used, which accelerates oil conversion and reduces acid content. The addition of catalyst and longer stirring time also help to break down fatty acid molecules, resulting in a higher saponification number. However, the analysis of variance showed that the variation of catalyst treatment had no significant effect on the saponification number, so DMRT analysis was not required.

*3.4* Total Glycerol

Total glycerol is an important indicator of successful biodiesel production and reflects its quality. It includes the amount of free glycerol, unreacted and partially reacted glycerol. A high total glycerol value indicates that the refining process may not be perfect and transesterification is not going well, which can harm the diesel engine [10]. The effect of KOH catalyst concentration and 60°C temperature on the total glycerol value is shown in Figure 5.

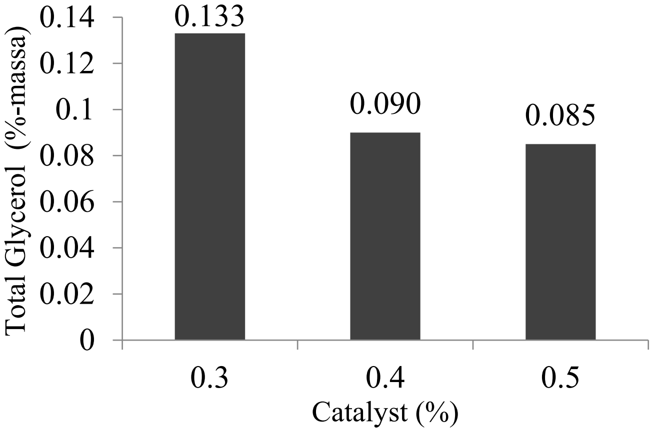

Figure 5. Graph of average value of total glycerol

Figure 5 shows that the variation of KOH catalyst concentration affects the total glycerol value, with 0.3% concentration producing the highest value of 0.133 (%-mass) and 0.5% concentration producing the lowest value of 0.085 (%-mass). Based on [11] the maximum total glycerol value is 0.24 (%-mass), so the results of this study are classified as good. Compared to [7] research, which used a static mixer type LPD without holes and produced a value of 0.092 (%-mass) at the same concentration, this study shows that the addition of holes in the LPD increases the yield of biodiesel production. Analysis of variance using a non-factorial Completely Randomized Design (CRD) showed that variations in catalyst concentration had a significant effect on total glycerol, which required further analysis with the Duncan Multiple Range Test (DMRT) (Table 1).

Table 1. DMRT test for total glycerol

| Interval | DMRT | | Treatment | Average | Notation | |
|---|---|---|---|---|---|---|
| | 0.05 | 0.01 | | | 0.05 | 0.01 |
| - | - | - | K3 | 0.085 | a | A |
| 2 | 0.023 | 0.032 | K2 | 0.090 | a | A |
| 3 | 0.024 | 0.033 | K1 | 0.133 | b | B |

Referring to Table 1, it can be seen that K3 catalyst has the lowest total glycerol value and is not significantly different from K2, but is significantly different from K1 sourced at the DMRT test at the 5% and 1% levels. This illustrates that the total glycerol value is strongly influenced by the use of catalysts. The lowest total glycerol was found in K3, which is 0.5% catalyst concentration. The decrease in the value of total glycerol content is caused by an increase in catalyst activity that will interact with fatty acids, so that more products form biodiesel and the total glycerol obtained is smaller.

### *3.5* Viscosity

According to [12], one of the objectives of transesterification of triglycerides into methyl esters is to reduce oil viscosity. Viscosity is the resistance of liquid flow through a capillary pipe that is influenced by gravity or flow pressure. Fuel should have a low viscosity so that it can flow and disperse well. However, too low a viscosity can reduce lubricity, potentially causing leaks in the pump. Conversely, high viscosity can result in slow fuel flow and difficulty atomizing [13]. The results of the viscosity test analysis in this study are presented in Figure 6.

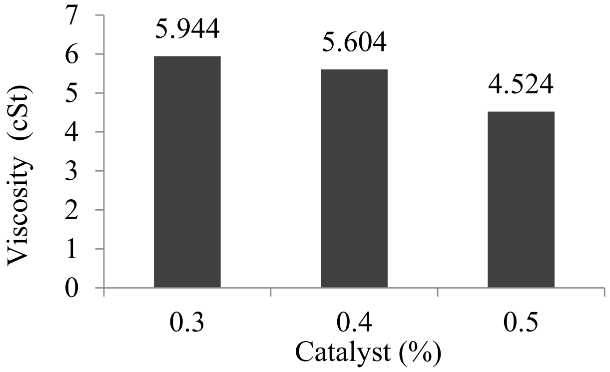

Figure 6. Graph of average viscosity values

Based on Figure 6, the average viscosity of biodiesel in this study meets the biodiesel quality standard, which is around 2.3 - 6.0 cSt. The average viscosity value shows a decrease as the catalyst concentration used increases. The 0.5% catalyst concentration produced the lowest viscosity of 4.524 cSt, while the 0.3% concentration gave the highest viscosity of 5.944 cSt. The decrease in viscosity shows that the catalyst concentration affects the triglyceride transesterification reaction in the formation of biodiesel. [14] explained that high viscosity is caused by the presence of tri-, di-, and mono-glycerides in biodiesel, which indicates that the methyl ester formation reaction is not optimal. The results of the analysis of variance with a non-factorial Completely Randomized Design (CRD) showed that variations in catalyst concentration had a significant effect on viscosity values, so it was necessary to conduct further tests using the Duncan Multiple Range Test (DMRT) (Table 2).

Table 2. DMRT test viscosity

| Interval | DMRT | | Treatment | Average | Notation | |
|---|---|---|---|---|---|---|
| | 0.05 | 0.01 | | | 0.05 | 0.01 |
| - | - | - | K3 | 4.525 | a | A |
| 2 | 0.2035 | 0.2814 | K2 | 5.604 | b | B |
| 3 | 0.2134 | 0.2935 | K1 | 5.944 | c | C |

Based on Table 2, the lowest viscosity was recorded in the K3 treatment, which showed significant differences compared to the other treatments, as evidenced by the DMRT test results at the 5% and 1% levels. This indicates that the variation in catalyst concentration has a major effect on viscosity. With increasing catalyst concentration, the possibility of methyl ester formation also increases, so viscosity tends to decrease. Higher concentrations accelerate the breakdown of triglycerides into three fatty acid esters, which contributes to the decrease in viscosity [15].

### *3.6* Methyl Ester Content

Methyl ester content is the main parameter for assessing biodiesel quality, reflecting how much triglyceride is converted to methyl ester. In this study, methyl ester content was calculated based on acid number, saponification number, and total glycerol using Equation 1. The results of the methyl ester content analysis are presented in Figure 7.

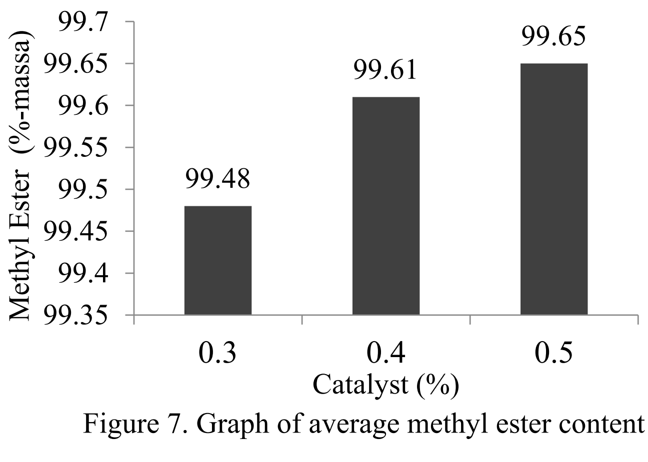

Figure 7. Graph of average methyl ester content

In Figure 7, it can be seen that the average methyl ester content increases as the catalyst concentration increases, with the lowest at 0.3% concentration at 99.48% and the highest at 0.5% concentration at 99.65%. All of these values are quite high and exceed the set biodiesel standard of 96.5% [11]. Analysis of variance using non-factorial CRD showed that variations in catalyst concentration had a very significant impact on methyl ester levels, so further analysis was carried out using DMRT as shown in Table 3.

Table 3. DMRT test for methyl ester content

| Interval | DMRT | | Treatment | Average | Notation | |
|---|---|---|---|---|---|---|
| | 0.05 | 0.01 | | | 0.05 | 0.01 |
| - | - | - | K1 | 99.48 | a | A |
| 2 | 0.051 | 0.071 | K2 | 99.62 | B | B |
| 3 | 0.054 | 0.074 | K3 | 99.65 | b | B |

The DMRT test results in Table 3 show that the lowest methyl ester content was produced by catalyst K1, which was significantly different from K2 and K3. K2 catalyst was not significantly different from K3, and both gave higher methyl ester content, with K3 at 0.5% concentration as the highest and K1 at 0.3% as the lowest. This indicates that increasing the catalyst concentration accelerates the transesterification process and increases the catalyst efficiency. Methyl ester content is also affected by acid number, saponification number, and glycerol content. [7] found that a catalyst concentration of 0.5% produced a methyl ester content of 99.64%, which increased by 0.01% when a perforated static mixer LPD was used, in accordance with [4] which showed an increase in methyl ester content with perforated static mixer elements.

### *3.7* Use of perforated LPD type static mixer against catalyst consumption and Study Limitations

The results showed that the biodiesel produced met quality standards in terms of acid number, saponification number, total glycerol, viscosity, and methyl ester content. This was achieved using a perforated LPD-type static mixer with an oil-methanol molar ratio of 1:6 and KOH catalyst concentrations of 0.3%, 0.4%, and 0.5% at 60°C. The 0.4% KOH catalyst produced a high methyl ester content, which was not significantly different from that of the 0.5% concentration, but more favorable in terms of cost efficiency and environmental impact.

Compared to the previous study [7], this research found no significant differences in acid number and viscosity; however, improvements were observed in total glycerol and methyl ester content. The addition of holes in the LPD-type static mixer contributed to better fluid dynamics by increasing the frequency of material collisions, resulting in a more homogeneous flow and enhanced transesterification reaction. As reported by [4], perforated LPD designs accelerate flow and improve mixing performance, which supports the formation of methyl esters from triglycerides.

Although the use of a Static Mixer Reactor (SMR), particularly the perforated LPD type, has demonstrated several advantages—such as more effective mixing without moving parts, reduced catalyst requirements, and a faster transesterification process—this method is not without limitations. Firstly, the experiment was only conducted using a limited range of KOH catalyst concentrations (0.3%, 0.4%, and 0.5%), which constrains the generalizability of the results. Secondly, the study was performed on a laboratory scale, making it uncertain whether the same efficiency would be achieved in larger, industrial-scale applications where flow dynamics and energy demands may vary significantly. Additionally, although the perforated design of the LPD static mixer enhanced the mixing process, no direct experimental comparison was conducted against unperforated mixers or traditional stirring systems. This limits a full evaluation of the mixer's relative effectiveness. Furthermore, energy efficiency claims were not supported by quantitative data, and aspects such as catalyst residue, waste treatment, and cost analysis were not addressed. These shortcomings highlight the need for further research to validate the benefits of the SMR method in broader operational contexts and to assess its scalability, environmental impacts, and economic feasibility.

## 4. Conclusion

The findings of this study confirm that the use of a perforated LPD-type static mixer in the catalytic biodiesel production process significantly improves the quality of biodiesel, as indicated by key parameters such as acid number, saponification number, total glycerol, viscosity, and methyl ester content. The variation in KOH catalyst concentrations (0.3%, 0.4%, and 0.5%) showed consistent trends where increased catalyst concentration generally led to better biodiesel characteristics.

The acid number decreased with higher catalyst concentrations, indicating more complete transesterification and lower levels of free fatty acids. Similarly, the saponification number increased, reflecting the conversion of triglycerides into esters. The lowest total glycerol value was observed at 0.5%

KOH, suggesting a more efficient reaction and purification process. In terms of viscosity, all treatments remained within the biodiesel standard (2.3–6.0 cSt), with lower viscosity at higher catalyst levels. The most important indicator, methyl ester content, reached 99.65% at 0.5% KOH, well above the minimum requirement of 96.5%.

However, despite the slightly higher values at 0.5%, the difference with 0.4% was not statistically significant. This implies that using 0.4% KOH provides a similarly high-quality biodiesel product but with greater cost and environmental efficiency, making it the optimal catalyst concentration in this study.

The perforated LPD mixer also contributed to better mixing performance compared to unperforated types, as supported by previous simulations and this experimental validation. The increase in turbulence and collision frequency within the mixer enhances mass transfer, which is crucial in transesterification processes involving immiscible reactants like oil and methanol.

In conclusion, the integration of a perforated LPD static mixer with 0.4% KOH catalyst concentration is an effective and efficient method for producing biodiesel that meets quality standards while reducing catalyst usage. Future studies are recommended to scale up this process and evaluate its performance and sustainability in industrial applications.

## References

[1] Direktorat Jendral Energi Baru Terbarukan Dan Konservasi Energi (EBTKE), *Pertamina Lakukan Penyaluran Perdana Biosolar B35 [Pertamina Carries Out Initial Distribution of B35 Biodiesel]*, Indonesia: Humas EBTKE, 2023.

[2] S. Panggabean, R. Sigalingging, Raju, “Simulation of Biodiesel Production Using Perforated Helical Type Static Mixer,” *IOP Conf. Ser.: Earth Environ. Sci.* vol. 454, no. 012045, 2020.

[3] Joelianingsih, A. Tambunan, H. Nabetani, Y. Sagara, K. Abdullah, “Perkembangan Proses Pembuatan Biodiesel Sebagai Bahan Bakar Nabati (BBN) [Development of the Biodiesel Production Process as a Biofuel (BBN)],” *Jurnal Keteknikan Pertanian*, vol. 20, pp. 205-216, 2006.

[4] Hashifatunnisa, S. Panggabean, “Study of Biodiesel Production Fluid Flow Patterns in LPD Type Static Mixing Reactors Using CFD Simulation For Sustainable Energy,” *IOP Conf. Seroes: Earth and Environmental Science,* vol. 977, pp. 1-8, 2022.

[5] I. Ghani, M. Ikhsan, U. Nizar, “Aplikasi Karbon Ampas Teh Tersulfonasi Sebagai Katalis Dalam Produksi Biodiesel dari Pfad (Palm Fatty Acid Destilate) [Application of Sulfonated Tea Dregs Carbon as a Catalyst in Biodiesel Production from PFAD (Palm Fatty Acid Distillate)],” *Prima Medical Journal (PRIMER),* vol. 4, pp. 1-6, 2021.

[6] H. Wijayanti, H. Nora, R. Amelia, “Pemanfaatan Arang Aktif dari Serbuk Gergaji Kayu Ulin Untuk Meningkatkan Kualitas Minyak Goreng Bekas [Utilization of Activated Charcoal from Ironwood Sawdust to Improve the Quality of Used Cooking Oil],” *Jurnal Teknik Konversi,* vol. 1, pp 27-33, 2012.

[7] N. Fazrina, “Kajian Penggunaan Static Mixer Tipe Heliks dan LPD (*low pressure drop*) Pada Proses Biodiesel Secara Katalitik [Study of the Use of Helical and LPD (Low Pressure Drop) Type Static Mixers in the Catalytic Biodiesel Process],” Undergraduate thesis, Universitas Sumatera Utara, Medan, 2020.

[8] G. N. Oktaningrum, “Pengaruh Konsentrasi Katalis KOH Dan Suhu Pada Proses Transesterifikasi In Situ Bungkil Wijen (Sesame Cake) Terhadap Produksi Biodiesel [The Effect of KOH Catalyst Concentration and Temperature on the In Situ Transesterification Process of Sesame Cake on Biodiesel Production],” Undergraduate thesis. Universitas Sebelas Maret. Surakarta, 2010.

[9] F. Dayanti, “Kajian Pengaruh Pemakaian Katalis (KOH) Pada Proses Produksi Biodiesel Dengan Menggunakan Static Mixing Reactor [Study of the Effect of Catalyst (KOH) Use on the Biodiesel Production Process Using a Static Mixing Reactor],” Undergraduate thesis. Universitas Sumatera Utara: Medan, 2020.

[10] A. Prihanto, B. Pramudono, H.Santosa, “Peningkatan Yield Biodisel dari Minyak Biji Nyamplung Melalui Transesterifikasi Dua Tahap [Biodiesel Yield Enhancement from Nyamplung Seed Oil Through Two-Stage Transesterification],” *Jurnal Momentum,* vol. 9, pp. 46-53, 2013.

[11] Kementrian Energi dan Sumber Daya Mineral Republik Indonesia, Standar dan Mutu (Spesifikasi) Bahan Bakar Nabati Jenis Biodiesel Sebagai Bahan Bakar Lain yang Dipasarkan Di Dalam Negeri [Standards and Quality (Specifications) of Biodiesel as an Alternative Fuel Marketed Domestically], 2022.

[12] Affandi, Formo, Gita, “Produksi Biodiesel dari Lemak Sapi dengan proses Transesterifikasi dengan Katalis Basa NaOH [Biodiesel Production from Beef Fat by Transesterification Process with NaOH Base Catalyst],” *Jurnal Teknik Kimia USU*, vol. 2, pp. 1-6, 2013.

[13] F. Aini, S. Tjahjani, “Hubungan Antara Waktu Penyimpanan dan Nilai Viskositas Biodiesel Minyak Biji Kapuk [Relationship Between Storage Time and Viscosity Value of Cottonseed Oil Biodiesel]”. *UNESA Journal of Chemistry,* vol. 2, pp. 35-41, 2013.

[14] S. Sari, A. Tambunan, L. Nugroho, “Penggunaan Pengaduk Statik Untuk Pengurangan Kebutuhan Katalis Dalam Produksi Biodiesel [Use of Static Stirrer to Reduce Catalyst Requirements in Biodiesel Production],” *Jurnal Teknologi Industri Pertanian,* vol. 26, pp. 236-245, 2016.

[15] I. Wiyata, R. Broto, “Pembuatan Biodiesel Minyak Goreng Bekas dengan Memanfaatkan Limbah Cangkang Telur Bebek Sebagai Katalis CaO [Making Biodiesel from Used Cooking Oil by Utilizing Duck Eggshell Waste as a CaO Catalyst],” *Jurnal Pengabdian Vokasi*, vol. 2, pp. 69-74, 2021.

.