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Addition of a Static Mixer as a Modification to the Chemical Reactant Feed Pretreatment for Reducing Monoglyceride Content

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ABSTRACT

Objective: *Biodiesel is a sustainable alternative energy that is continuously being developed. Monoglycerides are a contaminant component in biodiesel, causing blockages and abrasiveness in fuel injection. Reducing the monoglyceride component can be achieved using several technologies, one of which is the use of a static mixer to mix methanol (CH3OH) and sodium methoxide (CH3ONa) before being fed into the reactor to optimize the transesterification reaction.* ***Method:*** *This study first simulated the flow velocity profile and turbulence kinetic energy (TKE) in a pipe without a static mixer and a pipe with a static mixer using ANSYS Fluent 2025R1 software. The study consisted of 14 runs, 7 of which were performed without a static mixer and 7 with a static mixer. The production of each run was then analyzed for glyceride components using gas chromatography.* ***Results:*** *The maximum velocity in the pipe without a static mixer is 0.584 m/s and using a static mixer is 1.146 m/s, increasing by 96,2%. The turbulence kinetic energy (TKE) value in the pipe without a static mixer is 0.00235 m^2/s^2 and using a static mixer is 0.0282 m^2/s^2, indicating the presence of turbulent flow along the static mixer. The average percentage of monoglyceride components in the treatment without a static mixer is 0.4828% and with a static mixer is 0.4593%.* ***Novelty:*** *This research has never been conducted on a factory scale with a continuous production process so that it will help improve the quality of biodiesel, especially in reducing the monoglyceride component.*

INTRODUCTION

Significant energy is needed to support infrastructure and increasingly mobile facilities as a result of the world's increasingly advanced development. An energy crisis that affects numerous industries may result from unchecked energy consumption, especially for non-renewable energy sources like diesel fuel. Since most human activities rely on diesel fuel, its availability is essential. Non-renewable diesel fuel is becoming less accessible. The demand for diesel fuel is also rising as a result of advances in technology and the transportation industry [1].

In 2021, the main energy sources in Indonesia were primarily coal, oil, and natural gas, which together comprised around 87.8% of the overall energy consumption. Additionally, the transportation sector, being the highest consumer of energy, fulfilled 93.8% of its energy requirements using fuels derived from petroleum. This significant dependency on fossil fuels results in two critical effects: it strains foreign currency reserves because of import requirements, and it causes a rise in greenhouse gas emissions due to the burning of hydrocarbons that come from fossil fuel supplies [2].

The government of Indonesia is dedicated to promoting the use of various fuels in the transportation industry, especially by adopting biofuels (BBN), which exemplifies the energy transition strategy described in the National Energy Policy (KEN). The biofuel initiative in Indonesia commenced officially in approximately 2006, initially introduced to meet public service duties (PSO). Subsequently, this initiative became compulsory in 2008. There are multiple motivations for launching the biofuel program in Indonesia: it seeks to enhance energy security and stability, acts as a measure for poverty reduction, and aims to elevate environmental standards [3].

Biodiesel represents a renewable and safe fuel option created from fats and oils sourced from plants and animals. It is viewed as a superior choice because it generates fewer carbon emissions when burned, in contrast to traditional diesel fuels. In 2023, the Indonesian government's required biodiesel initiative aims for a production level of 12.2 billion liters, with a projected rise in usage of 2-4%, reaching 13.4 billion liters by 2024 [4].

The increasing use of biodiesel as fuel requires stricter quality treatment before being mixed with fossil diesel. This aims to anticipate damage to the engine such as blockage of fuel injection due to impurities in the fuel mixture [5]. Increasing the biodiesel concentration ratio in fossil diesel fuel increases the likelihood of deposits in fuel filters and the formation of large, abrasive particles that erode engine surfaces. These impurities can cause premature wear and reduce the precision of pumps and injector surfaces [6]. Monoglycerides are one of the impurities in biodiesel caused by the reversible reaction of triglycerides to glycerol, one of the steps of which includes the formation of diglycerides and monoglycerides [7].

Reducing the monoglyceride content in biodiesel is continuously carried out to obtain high-quality biodiesel. Research conducted by Srikwanjay et al (2019) used a low-temperature adsorption technique using natural zeolite (NZ 325m) which resulted in a reduction in monoglyceride from 0.7%wt to 0.35%wt [8]. On a larger scale production, this technique is difficult to implement because it requires large costs for the provision of adsorbents and the treatment required for activation of the adsorbent when it is saturated. Gozan et al (2022) reduced the monoglyceride content by sedimenting samples for 21 days where the results showed a decrease in monoglyceride content in biodiesel samples. Reducing monoglycerides using this sedimentation technique requires a large tank and a height-to-diameter ratio that needs to be taken into account [9]. Fuad and Kurniawan (2022) used a distillation technique (column plates) in their research, which reduced monoglycerides from 0.83%wt to 0.17%wt at a distillation temperature of 240-325 ^{o}C. This technique significantly reduced monoglycerides but required significant heat energy for its operation [10].

This study focuses on the optimization of the transesterification reaction to reduce monoglycerides component. This reaction optimization follows the research conducted by Sinaga et al (2025) by mixing the reactants methanol (CH_3OH) and sodium methoxide (CH_3ONa) as a catalyst first [11]. In this study, the chemical mixing path was modified with the addition of a static mixer to obtain a more homogeneous mixing between the reactants methanol (CH_3OH) and sodium methoxide (CH_3ONa) before being reacted with refined bleached deodorized palm oil (RBDPO) in the reactor. The static mixer model used uses a 90^0 baffle angle to obtain a more even mixing [12]. This research provides a solution to reduce monoglyceride content by modifying equipment that is simpler and easier to apply to existing equipment and continuous processing.

RESEARCH METHOD

This research was conducted in the biodiesel department of PT X located in Riau, Indonesia with a biodiesel processing capacity of 25,000 kg/hr. This study aims to analyze the effect of adding a static mixer with a 90^0 baffle angle on the mixing path of methanol (CH_3OH) and sodium methoxide (CH_3ONa) before being reacted with refined bleached deodorized palm oil (RBDPO) in the reactor. The material specifications used in the processing process are: RBDPO includes FFA 0.08% - 0.1%, impurities 0.08% - 0.1%, and color 3.0/3.0 R/Y; methanol (CH_3OH) with a water content of 1000 ppm; sodium methoxide (CH_3ONa) with a water content of 2000 ppm and alkalinity of 30%. The equipment used includes methanol (CH_3OH) pumps (flow velocity 0.55 m/s) and sodium methoxide (CH_3ONa) (flow velocity 0.038 m/s) with an operational pressure of 3.2 bar; piping; 2 reactors with a capacity of 150 tons and a static mixer.

The processing was carried out by feeding RBDPO into the reactor with a flow rate of 25,000 kg/hr followed by the addition of 19.54%wt of methanol (CH_3OH) and 1.5%wt of sodium methoxide (CH_3ONa). After the reaction had been running for 6 hours, biodiesel was obtained as the main product and glycerol as a by-product. Biodiesel was then analyzed using gas chromatography (GC) to determine the glyceride content which includes monoglyceride, diglyceride and triglyceride. This study was conducted for 14 runs (days) where the first 7 days of the processing process were carried out without pathway modification and the next 7 days of the processing process using pathway modification, namely the addition of a static mixer.

The static mixer with a 90^o baffle angle used in this study was adopted from the research of Turgut et al [12] where this static mixer is the most optimal in assisting mixing in the flow in the pipe. Furthermore, after the installation of the static mixer, its effect on reducing the monoglyceride content during processing will be observed. The dimensions of the static mixer used in this study are as follows:

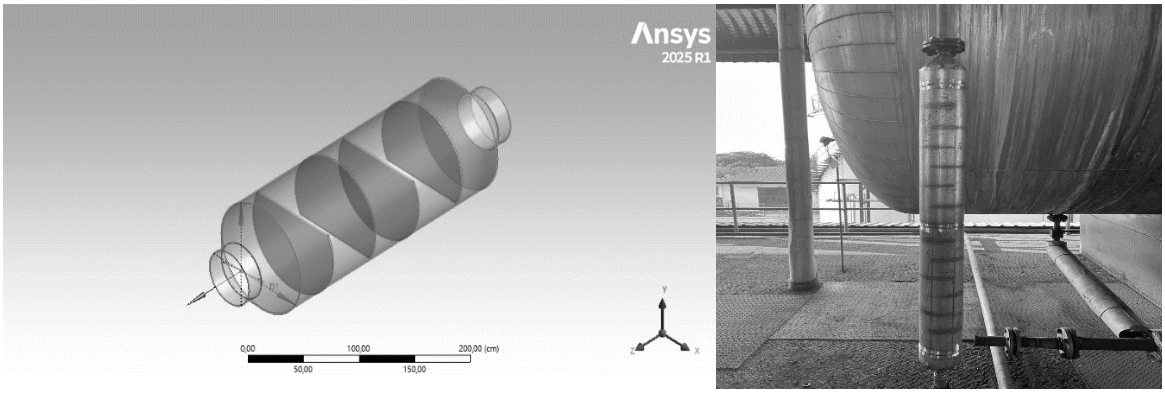

Figure 1. Static mixer design.

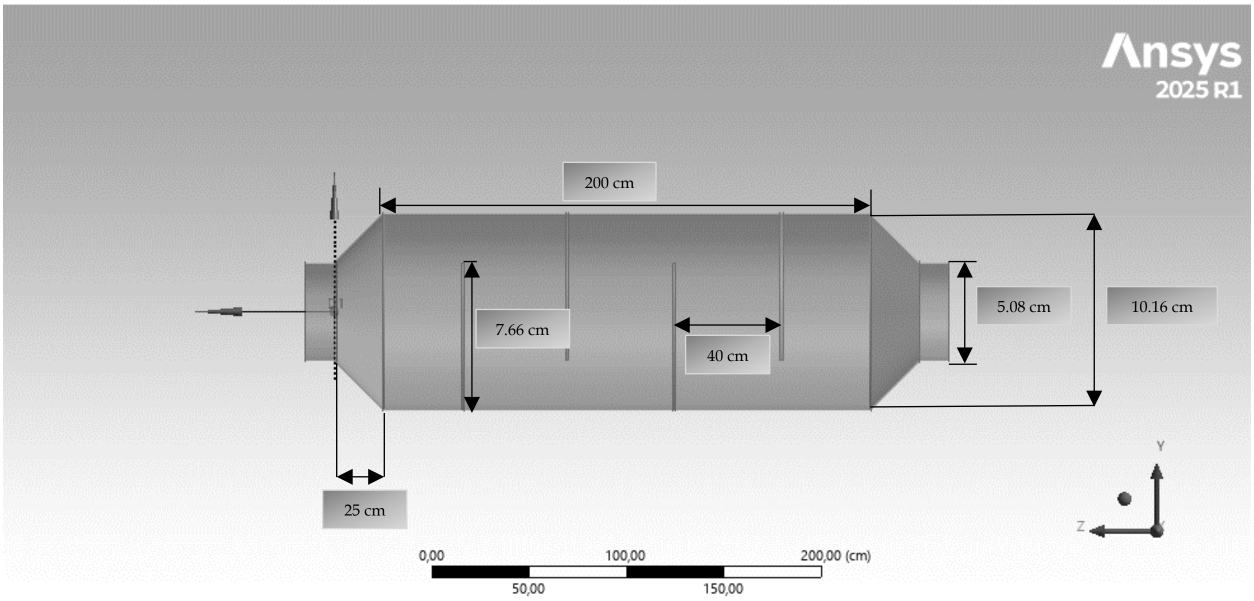

Figure 2. Static mixer dimensions.

This study also conducted a comparative simulation of flow distribution analysis in the pipe before and after the addition of a static mixer using ANSYS Fluent 2025R1 software with the K-epsilon (K-ε) turbulence model. This simulation will help analyze the flow distribution and mixing between methanol (CH_3OH) and sodium methoxide (CH_3ONa).

RESULTS AND DISCUSSION

Analysis of The Mixing Flow Distribution

Analysis of the mixing flow distribution of methanol (CH_3OH) and sodium methoxide (CH_3ONa) in the pipe before and after the addition of a static mixer was performed using ANSYS Fluent 2025R1 simulation. The simulation examined the velocity contours and turbulence kinetic energy (TKE) of the flow.

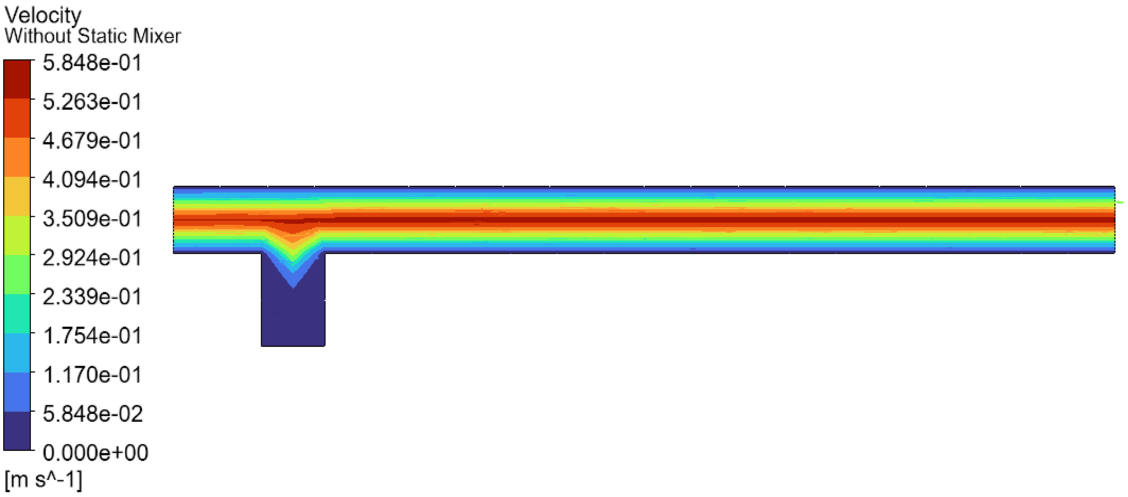

Figure 3. Velocity contours of mixing between methanol (CH_3OH) and sodium methoxide (CH_3ONa) without static mixer.

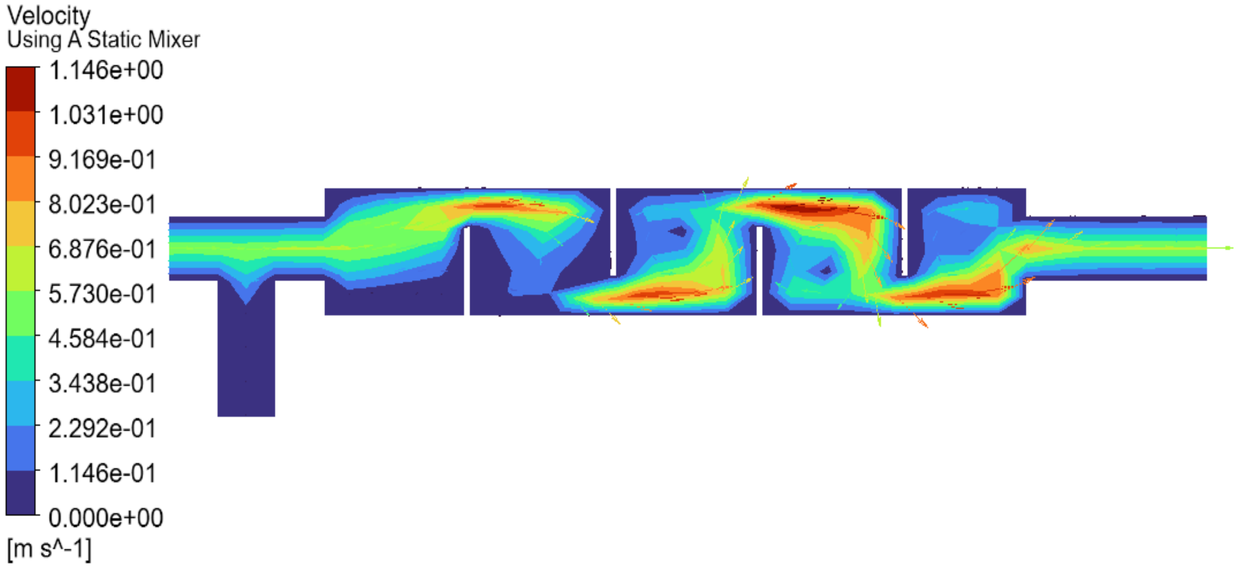

Figure 4. Velocity contours of mixing between methanol (CH_3OH) and sodium methoxide (CH_3ONa) through static mixer.

Figure 3 and Figure 4 shows the velocity contours of mixing methanol (CH_3OH) and sodium methoxide (CH_3ONa) in a pipe without a static mixer and through a static mixer. Figure 3 shows the dominant fluid flow velocity in the middle of the pipe with a maximum value of 0.584 m/s where this velocity predominantly comes from methanol (CH_3OH) which has a lower viscosity than sodium methoxide (CH_3ONa). The fluid velocity will change significantly starting from the wall at 0 m/s causing a violation to the optimum velocity in the free flow of the upper layer [13]. This condition results in the mixing between methanol (CH_3OH) and sodium methoxide (CH_3ONa) not occurring evenly as can be seen from the simulation results which show the uniformity of the velocity profile in the pipe without a mixer which is a property of laminar flow [14]. Figure 4 shows changes in the velocity profile after the pipe is added to the static mixer where the velocity is not uniform and random movement is obtained in the mixing of methanol (CH_3OH) and sodium methoxide (CH_3ONa). The addition of a static mixer with a 90^o baffle angle increases the flow velocity to a maximum value of 1,146 m/s (increased by 96.2%) at several points in the static mixer. The difference in cross-sectional area along the pipe passed by the fluid will break the flow into small vortices which will have an impact on increasing the mixing of components in the fluid [15].

Figure 5 and Figure 6 shows the turbulence kinetic energy (TKE) simulation of methanol (CH_3OH) and sodium methoxide (CH_3ONa) fluid flow through a pipe without a static mixer and a pipe with a static mixer. Figure 5 provides a simulation of a maximum TKE value of 0.00235 m^2/s^2 at the end of the pipe. The further the fluid distance from the pipe inlet, the higher the TKE value obtained. In contrast, Figure 6 shows that at several points along the fluid flow in a static mixer, the maximum TKE value is 0.0282 m^2/s^2, which is greater than the TKE value through a straight pipe.

The turbulent kinetic energy generated from the collision of a system and some of the TKE will be lost and the rest is used to increase the potential energy [16]. One of the parameters used to determine the flow profile is turbulence through the TKE value. The higher the TKE value will increase the vortex in the flow which indicates higher mixing and turbulence in the fluid [17]. The provision of a 90° angle baffle on a static mixer provides a turbulence effect around the baffle so that mixing is more optimal. This can also be seen from the vector simulation in Figure 6 which displays a random pattern on the baffle section which indicates the presence of eddies and turbulent flow.

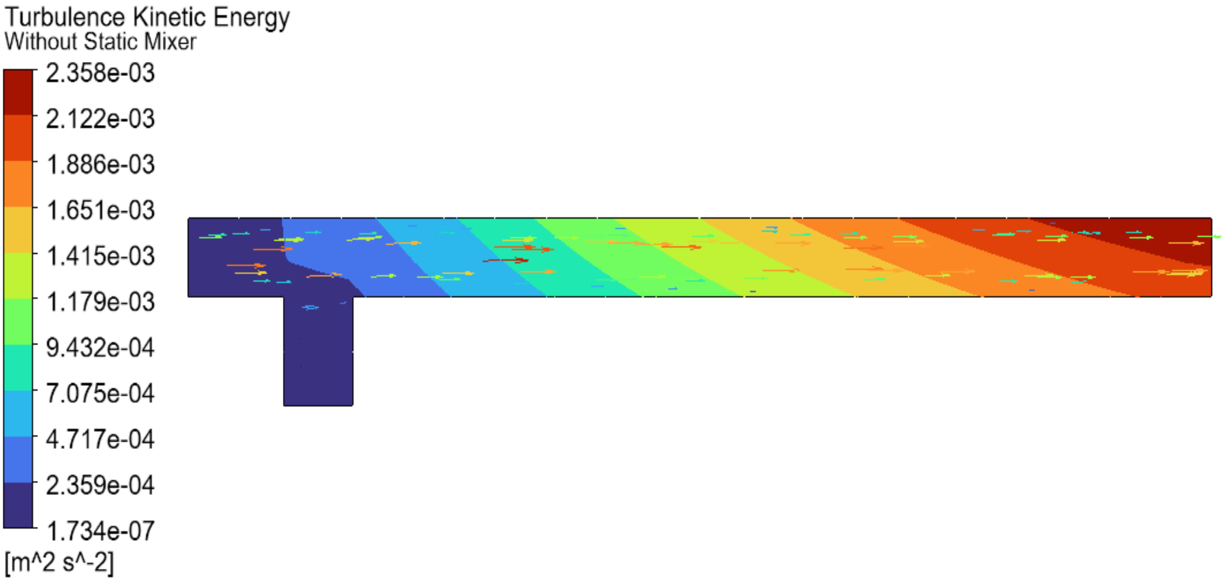

Figure 5. Turbulance kinetic energy contours of mixing between methanol (CH_3OH) and sodium methoxide (CH_3ONa) without static mixer.

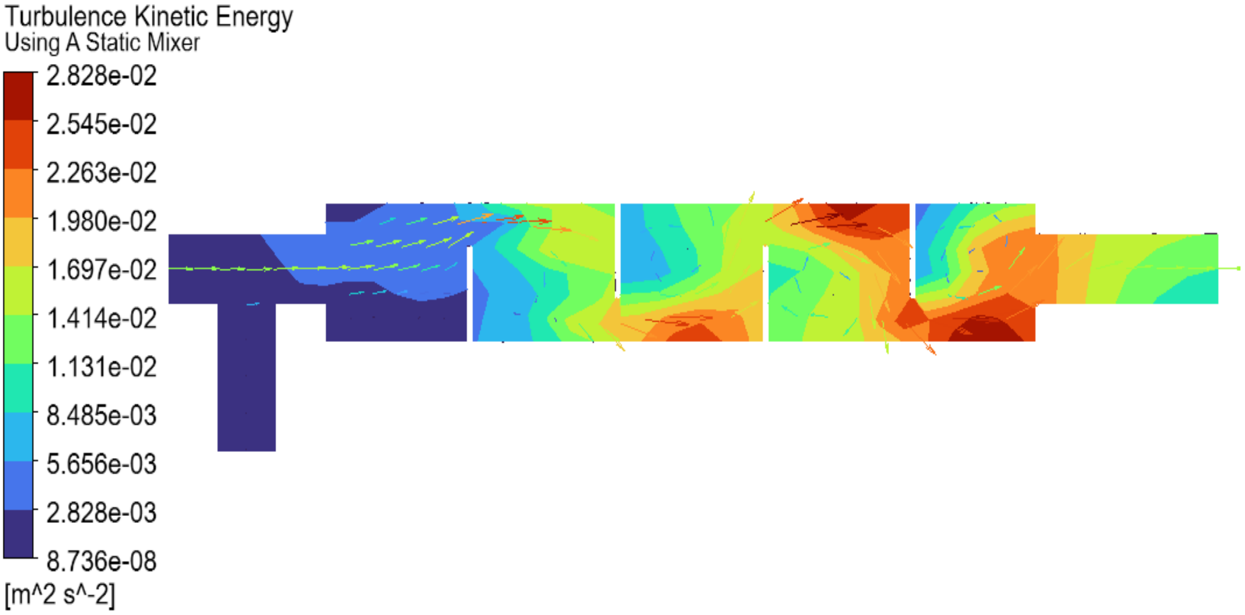

Figure 6. Turbulance kinetic energy contours of mixing between methanol (CH_3OH) and sodium methoxide (CH_3ONa) through static mixer.

Analysis of Biodiesel Glyceride Components

The biodiesel produced was then analyzed using gas chromatography (GC) to determine the amount of glyceride remaining in the biodiesel. Figure 5 shows the characteristics of the glycerides contained in the biodiesel as follows:

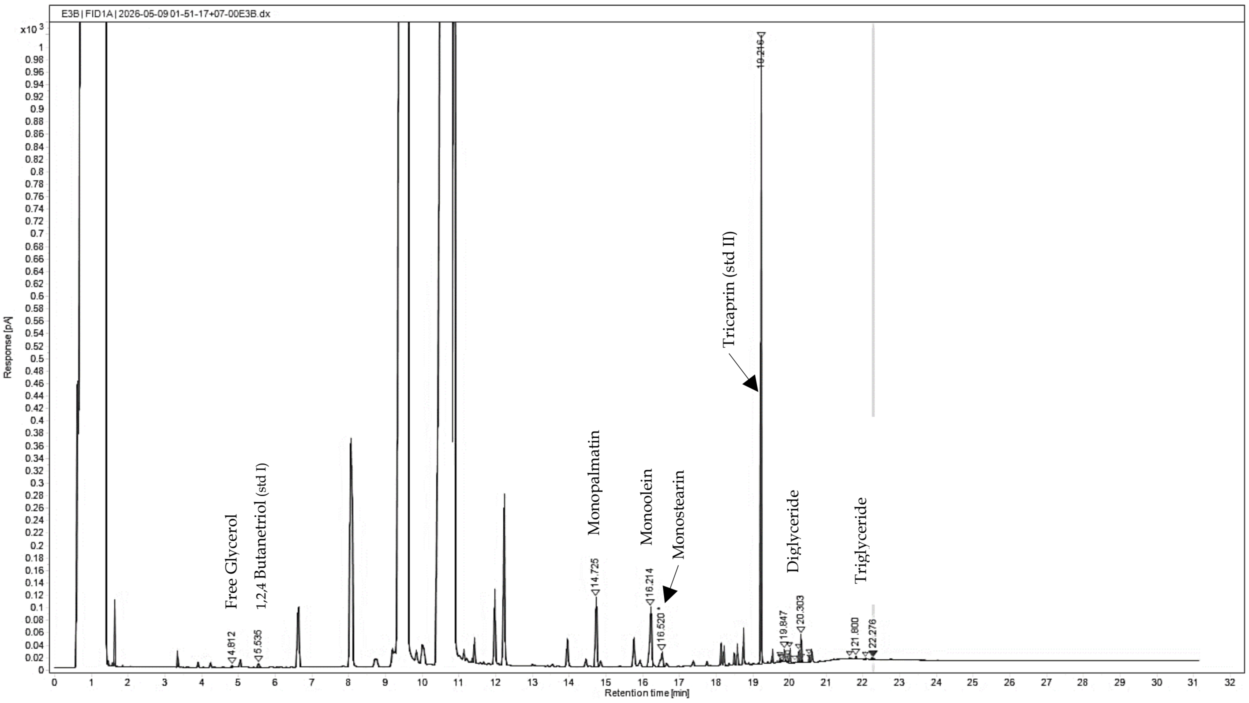

Figure 7. Analysis results of glyceride characteristics in biodiesel using gas chromatography (GC)

Figure 7 shows the glyceride components in the biodiesel produced, including monoglyceride components (monopalmatin, monoolein, monostearin), diglyceride and triglyceride at each retention time.

Table 1. Result of glyceride component in biodiesel.

Component	Retention Time (minutes)
Monopalmatin	14.725
Monoolein	16.214
Monostearin	16.520
Diglycerides	19.847
Triglycerides	21.800

After the retention time of each glyceride component is obtained, the percentage of components in biodiesel is calculated as shown in Table 2. Table 2 shows the percentage of each glyceride component in biodiesel where there are 14 runs (days) with run 1-7 process treatment without using a static mixer and run 8-14 using a static mixer. The results obtained from run 1-7 average monoglycerides of 0.4828 %wt while using a static mixer run 8-14 average monoglycerides of 0.4593 %wt. The use of a static mixer in the methanol (CH_3OH) and sodium methoxide (CH_3ONa) mixture path has an effect on reducing glycerides in biodiesel components, especially monoglycerides. This study is supported by Sinaga et al. (2025) that mixing methanol (CH_3OH) and sodium methoxide (CH_3ONa) at a certain time duration can help optimize the transesterification reaction [11]. The addition of a static mixer to the piping has the aim of increasing the mixing between the methanol (CH_3OH) and sodium methoxide (CH_3ONa) mixture. The higher the mixing of this adhesive will increase the concentration of sodium methoxide (CH_3ONa) in the solution which has an impact on the efficiency of the transesterification reaction. The use of methanol (CH_3OH) and sodium methoxide (CH_3ONa) industrially has a weakness, namely the high air content. The presence of air in the sodium methoxide (CH_3ONa) solution will also cause a reversible reaction to form methanol (CH_3OH) and sodium hydroxide (NaOH) components, which will result in side reactions such as saponification reactions throughout the transesterification process [18]. To prevent this from happening, the use of methanol (CH_3OH) which is more in accordance with the L'Chatelier principle will maintain the equilibrium of the reactants and increase the concentration of sodium methoxide (CH_3ONa) in the solution is maintained or even increased [19]. The use of a static mixer in the pipeline increases the mixing of methanol (CH_3OH) and sodium methoxide (CH_3ONa) as seen from the change in laminar flow to turbulent around the baffle and an increase in the turbulence kinetic energy (TKE) value along the static mixer.

Table 2. Percentage glyceride component in biodiesel.

Run (Days)	Process Treatment	Glycerides Component (% wt)		
		Monoglyceride	Diglyceride	Triglyceride
1	Without Static Mixer	0.4829	0.1785	0.1624
2		0.4821	0.1759	0.1610
3		0.4885	0.1723	0.1614
4		0.4844	0.1772	0.1519
5		0.4795	0.1785	0.1528
6		0.4820	0.1610	0.1524
7		0.4801	0.1605	0.1524
8	Using Static Mixer	0.4622	0.1592	0.1551
9		0.4626	0.1582	0.1555
10		0.4620	0.1576	0.1557
11		0.4629	0.1574	0.1547
12		0.4612	0.1598	0.1552
13		0.4519	0.1536	0.1540
14		0.4520	0.1577	0.1546

CONCLUSION

Fundamental Finding : The addition of a static mixer to the mixing pipe of methanol (CH_3OH) and sodium methoxide (CH_3ONa) provides a better and more even mixing flow profile change seen from the velocity vector profile and the increased turbulence kinetic energy value. The better mixing of methanol (CH_3OH) and sodium methoxide (CH_3ONa) helps maintain the concentration of sodium methoxide (CH_3ONa) in the solution before it is reacted. **Implication :** The addition of a static mixer has the effect of reducing the monoglyceride content. This will help companies improve the quality of biodiesel for blending with fossil diesel at higher ratios at lower costs. **Limitation :** This research is the initial research on the use of a static mixer in mixing methanol (CH_3OH) and sodium methoxide (CH_3ONa) so that an analysis of the effect of the residence time of the reactants in the static mixer has not been carried out. **Future Research :** Further research will explore the residence time and the use of other types of baffles to ensure the effectiveness of the static mixer used in reducing the monoglyceride content in biodiesel.

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