Science and Technology Indonesia
e-ISSN:2580-4391 p-ISSN:2580-4405
Vol. 9, No. 1, January 2024

Research Paper

Kinetics of Homogeneous Reaction of Potassium Methoxide Based on K_2CO_3 Catalyst in Transesterification of RBDPO to Biodiesel

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Abstract
Biodiesel production is generally catalyzed by potassium methylate or sodium methylate catalysts based on KOH and NaOH and these catalysts are still imported. The search for a cheap and effective catalyst continues to be carried out by researchers. One of the catalyst support materials currently in use involves impregnating K_2CO_3 with various substances, resulting in a heterogeneous catalyst. In this study, it was tried to use K_2CO_3 dissolved in methanol to produce a homogeneous potassium methylate catalyst. Potassium methylate-based homogeneous catalyst K_2CO_3-methanol is proven to have a very high function in the transesterification reaction of Refined Bleached Deodorized Palm Oil (RBDPO) into biodiesel, this is evidenced by the use of a catalyst percentage of 2% w and 30% w methanol to the weight of RBDPO resulting in an acid content in biodiesel of only 0.12% and a total glycerol of 0.124% in reaction time 3 hours, with the purity of the methyl ester in biodiesel reaching 98.80%. Meanwhile, for the calculation of homogeneous reaction kinetics, a reaction rate equation is produced where the order of the RBDPO transesterification reaction is order 2 (two) and the reaction rate constant is 0.0044.

Keywords
Catalyst, K_2CO_3, RBDPO, Kinetics of Homogeneous Reactions

Received: 11 July 2023, Accepted: 16 October 2023
https://doi.org/10.26554/sti.2024.9.1.28-35

1. INTRODUCTION

The mono-alkyl esters, most commonly the methyl esters, of vegetable oils, animal fats or other materials consisting mainly of triacylglycerols, often referred to as biodiesel, are an alternative to conventional petrodiesel for use in compression-ignition engines (Knothe and Razon, 2017). The use of biodiesel as fuel also can reduce pollutants such as CO_2, SO_2, CO, and hydrocarbon gases (Rodiah et al., 2020). Generally, biodiesel is produced from the transesterification reaction of triglycerides with alcohol in the presence of an alkaline catalyst. The hydroxides NaOH, KOH and methoxide $NaOCH_3$, $KOCH_3$ are the most active homogeneous catalysts for biodiesel production (Farobie and Matsumura, 2017; Thinnakorn and Tscheikuna, 2014). The market price of commercial methoxide solutions in methanol is significantly higher than hydroxide, but it is a superior catalyst for biodiesel production, as it contains high concentrations of methoxide ion (CH_3O^-) in the absence of water. For this reason, research and studies on transesterification catalysts that are cheaper continue to be investigated.

Potassium Carbonate (K_2CO_3) is a compound in the form of a white powder that is easily soluble in water, but insoluble in alcohol (ethanol) and is commonly used in yeast, ceramics, explosives, fertilizers, chemical intermediaries, and as a catalyst. Potassium Carbonate can be obtained from wood and agricultural waste when it is burned to ashes. K_2CO_3 is one of the most useful compounds used in industrial applications and can be obtained from organic or inorganic sources (Malins, 2018).

Among the various alkaline catalysts that are currently widely studied is potassium derived from K_2CO_3. K_2CO_3 can be used as a solid base catalyst in biodiesel production because of its high activity, low cost, and reusability. Liu et al. (2011) stated that K_2CO_3 is one of the most effective compounds and has sufficient basic strength to catalyze the transesterification reaction of fatty acid glycerides with alcohols.

Several researchers have applied K_2CO_3 as a heterogeneous catalyst and generally, they stated that among the alkali metal salts, K_2CO_3 has shown high transesterification activity and can be supported by Al_2O_3, MgO, and activated carbon as a solid base catalyst (Liu et al., 2011).

Turnip et al. (2017) researched on making biodiesel from used cooking oil waste using a K_2O catalyst from cocoa shell waste. Variation of weight percent of catalyst, namely 4, 5, and 6%, and variations of time 2, 3, and 4 hours with a molar ratio of methanol : oil 12:1 with 500 rpm rotation. From the results of this study it is known that the best conditions were obtained with the amount of catalyst 6% (w/w) which was calcined at 650°C, reaction time of 180 minutes, the mole ratio of alcohol and used cooking oil was 12:1 and the reaction temperature was 65°C, purity and yield the biodiesel produced is 99.58%.

Taslim et al. (2018) researched on making biodiesel from rice bran oil through a transesterification reaction using a heterogeneous natural zeolite catalyst modified with K_2CO_3. The molar ratios of methanol to rice bran oil were varied, namely 1:8, 1:10, and 1:12. The amount of natural zeolite/ K_2CO_3 catalyst varied from 2-4% w/w. The reaction temperature is 65°C and the stirring speed is 500 rpm. Reaction time 2-4 hours. From the research results it was found that natural zeolite modified with K_2CO_3 could be used as a heterogeneous catalyst in the manufacture of biodiesel from rice bran oil and provided a higher yield of biodiesel compared to unmodified natural zeolite. The highest biodiesel yield of 98.18% was obtained at the condition of the methanol-oil molar ratio of 10:1, the reaction time was 3 hours, and the amount of catalyst was 4%w/w.

Production of biodiesel from solar oil using a catalyst K_2CO_3 which was impregnated with Talc was carried out by Salmasi et al. (2020). The results of his research showed that the greater the percentage of K_2CO_3 the alkaline nature of the catalyst is higher which makes the greater the activation of K_2O so that the greater the yield of biodiesel produced K_2CO_3 used up to 40% w.

Cao et al. (2022) focus on researching the manufacture of biodiesel from used oil and see how the performance of the catalyst with K_2CO_3 as a catalyst support synthesized with MgO/CNT (carbon nano tube) which has high tensile strength, high flexibility, high activation and large active surface area (Kowthaman, 2020). With 4%w catalyst (MgO/CNT/K_2CO_3), a 4-hour reaction time, and a 20:1 methanol : oil ratio, the resulting yield reached 98.25%.

Munawar et al. (2020) researched on the synthesis of biodie sel from Refined Bleached Deodorized Palm Oil (RBDPO) by transesterification reaction using carbon-based on durian shells modified with KOH as a heterogeneous catalyst. Durian shell carbonization was carried out at 600°C for 2 hours. The resulting carbon was modified by impregnation with KOH followed by drying and calcination. The molar ratio of methanol to RBDPO oil was 12:1, the operating temperature was 60°C, the stirring speed was 500 rpm, the amount of catalyst was varied from 2-4% w/w, and the reaction time was varied from 60-150 minutes. The highest biodiesel yield of 97.29% was obtained with a reaction time of 90 minutes and a catalyst of 3% w/w.

By dissolving a certain amount of alcohol (methanol or ethanol), potassium metal will be extracted into the alcohol and it is hoped that it will react further to form a methoxide salt if methanol is used. This salt will help speed up the process of transesterification of vegetable oil (Sibarani et al., 2007).

Junior et al. (2019) used a K_2CO_3 catalyst with alumina support and the conversion of sunflower oil into biodiesel was 99.3% where the percent ratio was 35% K_2CO_3/65% γ-Al_2O_3, reaction temperature of 80°C and 1:12 oil: ethanol molar ratio. When they increased the % K_2CO_3, the yield decreased due to agglomeration on the active surface of the catalyst which affected its catalytic activity.

From some of the references above researchers have used K_2CO_3-based catalysts by combining several materials as catalyst supports such as Junior et al. (2020) with γ-Al_2O_3, Cao et al. (2022) preparing K_2CO_3 as a catalyst support synthesized with MgO/CNT (carbon nano-tube), Turnip et al. (2017) using a K_2O catalyst from cocoa shell waste and Foroutan et al. (2021) examined the performance of a combined biochar/CaO/K_2CO_3 catalyst. All of these researchers made heterogeneous catalysts based on K_2CO_3 and the highest yield produced was 99.3% which was produced by Junior et al. (2019). Therefore, this research focuses on using K_2CO_3 catalyst which was dissolved with methanol so that it became a homogeneous catalyst for making biodiesel. The consideration is that the biodiesel industry all uses KOH-based homogeneous catalysts, so if the performance of this catalyst is good and stable, then it can be applied directly to the biodiesel industry as a potassium methylate catalyst based on KOH-methanol but at a competitive price with potassium methylate produced from K_2CO_3-methanol. The most important parameters in assessing the performance of the catalyst are the total acid and glycerol content in biodiesel. With these two parameters, the methyl ester content in biodiesel is determined, and the kinetics of the RBDPO transesterification reaction are also determined.

2. EXPERIMENTAL SECTION

2.1 Materials

The raw material for the oil used is Refined Bleached Deodorized Palm Oil (RBDPO), obtained from PT. Sumi Asih in Bekasi Regency, West Java, the catalysts used are technical K_2CO_3 and technical Methanol production from Smart Lab. The characteristics of the RBDPO used contained dominant fatty acid compounds, namely about 44% palmitic fatty acid and about 43% oleic fatty acid with an acid number of 0.2%. The solvent used is technical smartlab methanol with a concentration of 70%, and the catalyst used is technical K_2CO_3 from Smartlab. The purity of K_2CO_3 analyzed by titration method was 89.97%.

2.2 K_2CO_3 Catalyst Synthesis

The catalyst synthesis of technical K_2CO_3 begins with the evaporation of water contained in K_2CO_3 because K_2CO_3 is very hygroscopic. After that, the K_2CO_3 catalyst was synthesized with methanol to obtain a homogeneous K_2CO_3 catalyst by dissolving K_2CO_3 in methanol. Methanol to RBDPO ratio 30%w/w. Dissolving K_2CO_3 was carried out by heating while stirring with a magnetic stirrer until all K_2CO_3 dissolved and

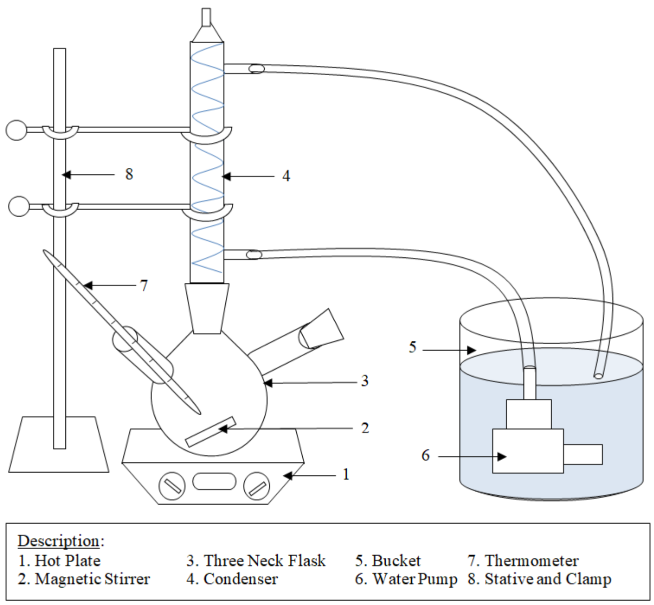


Figure 1. Description and Equipment RBDPO Transesterification

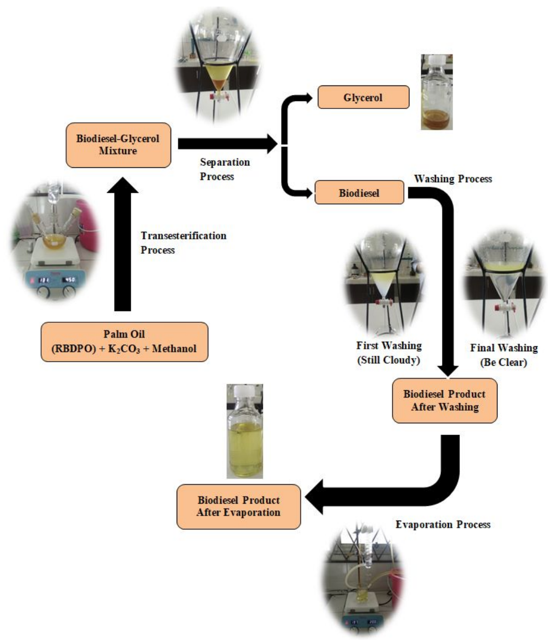


Figure 2. RBDPO Transesterification Flowchart with K_2CO_3 Catalyst

$$K_2CO_3 + CH_3OH \longleftrightarrow CH_3OK + KHCO_3$$

Potassium Carbonate; Methanol; Potassium Methoxide; Potassium Bicarbonate

Figure 3. Formation of Potassium Methoxide Reaction (Chanakaewsomboon et al., 2021)

the K_2CO_3 homogeneous catalyst was ready to be used in the transesterification reaction for making biodiesel.

2.3 Methods

The equipment used is a three-neck flask equipped with a condenser to keep the reaction temperature more stable as can be seen in Figure 1.

The RBDPO transesterification reaction process was carried out by adding 2% w/w K_2CO_3 catalyst. Where K_2CO_3 was previously dissolved in methanol to obtain a homogeneous catalyst. The catalyst is intended to break the chemical chain of vegetable oil so that the ester chain of vegetable oil will be released, once the ester is released, methanol will immediately react with it and form biodiesel, while the remaining glycerin and catalyst will precipitate after the reaction is complete. The stages of the RBDPO transesterification reaction can be seen in Figure 2.

2.4 RBDPO Transesterification Process with K_2CO_3 Catalyst

A set of three neck flask + attributes (thermometer, magnetic stirrer, and condenser) was prepared. RBDPO was heated using a hot plate at a temperature of 60-65°C for 10 minutes and then put into the three-neck flask. Put the mixture of methanol and K_2CO_3 earlier into the three-neck flask which already contains RBDPO oil. The transesterification process was carried out at 65°C with a variation of the reaction time that has been determined with a magnetic stirrer stirring speed of 450 rpm. Put the reaction product of the mixture of methyl ester and glycerol into the separating funnel and then wait about 30 minutes until the two mixtures are completely separated. After 30 minutes, the glycerol was separated from the separating funnel into a beaker glass. The methyl ester that was still in the separating funnel was then washed by spraying it with warm water at around 50°C repeatedly until the water was clear. The washed methyl ester was put into a beaker glass and then evaporated with a stirred hot plate at a temperature of 100-110°C for 1 hour to remove water and other impurities. The evaporated methyl ester was then put into a beaker glass to be weighed. The methyl ester was filtered with filter paper, and then the methyl ester was put into a glass bottle to be tested for characteristics such as Acid Number using the ASTM D 664 method and Total Glycerol using the ASTM D 6584 method. If the biodiesel product has been analyzed for its Acid Number and Total Glycerol values, then the methyl ester content can be calculated based on Equation (1).

Methyl Ester Content (%) :

$$\%ME = \frac{(100 \times (198 - AA - (18,29 \times TG))}{198} \quad (1)$$

AA = Acid Number

TG = Total Glycerol

198 = Saponification number for CPO

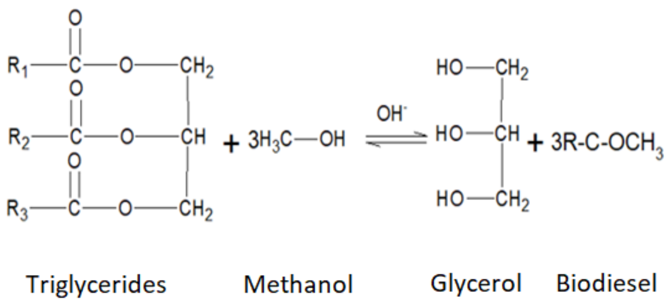


Figure 4. FAME Formation Reaction (Fessenden and Fessenden, 1986)

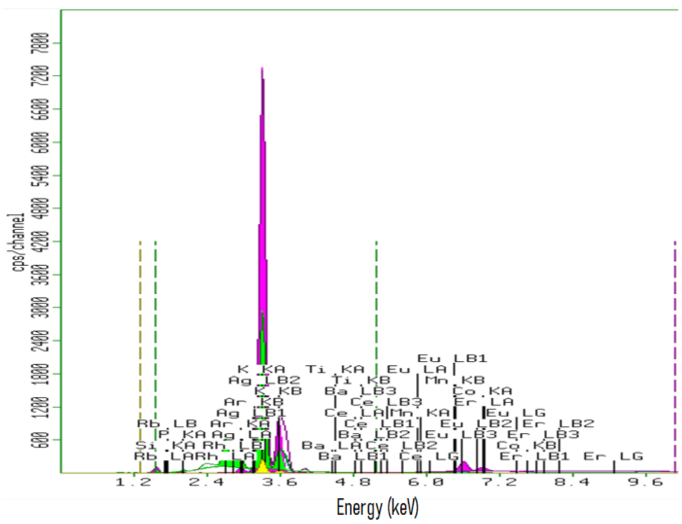


Figure 5. Chromatogram XRF Analysis Composition of Oxide Compounds in K_2CO_3

2.5 Kinetics of Homogeneous Reaction of K_2CO_3 Based Potassium Methoxide Catalyst

The transesterification reaction or methanolysis reaction is the reaction of triglycerides (vegetable oil) with methanol to produce fatty acid methyl esters (Fatty Acids Methyl Ester, FAME) and a by-product, namely glycerol. The transesterification reaction process was assisted by the role of an alkaline catalyst, namely a potassium methoxide-based K_2CO_3 catalyst can be seen in Figure 3. The transesterification reaction mechanism of triglycerides with methanol can be seen in Figure 4.

In this study, the kinetics of a homogeneous reaction was determined based on the solubility level of the K_2CO_3 catalyst in methanol solvent where the reactant phase (raw material) is the same as the catalyst phase, so it is assumed that the RBDPO transesterification reaction in a stirred reactor with a closed system (batch) is a homogeneous phase.

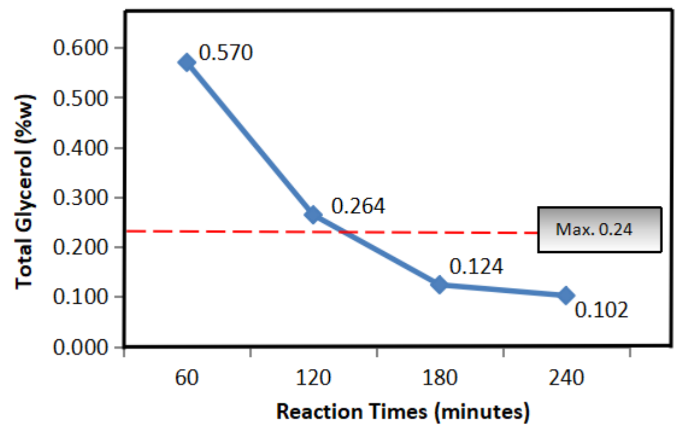


Figure 6. Effect of Reaction Times on Total Glycerol Content in Biodiesel with K_2CO_3 Catalyst

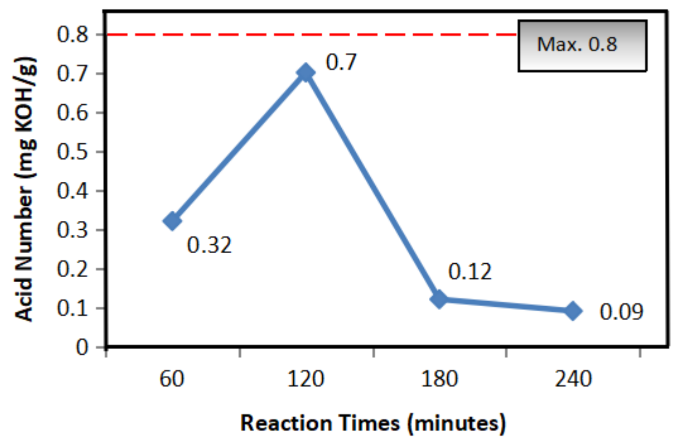


Figure 7. Effect of Reaction Times on Acid Number in Biodiesel

3. RESULTS AND DISCUSSION

3.1 Characteristics of K_2CO_3 Catalyst

The K_2CO_3 catalyst used is technical K_2CO_3 from Smart Lab. Before being used as a catalyst, the characteristics of K_2CO_3 were analyzed for its chemical composition by X-ray fluorescence (XRF), where it is known that X-ray fluorescence (XRF) is a non-destructive elemental analysis method for the qualitative and quantitative determination of the chemical composition of solids and liquids. This involves determining the element with a higher atomic weight than fluorine ($Z > 9$). The results can be seen in Figure 5 and Table 1.

From Table 1, it can be seen that the composition of the largest oxide compound is 96.474% K_2O, followed by 1.806% Ag_2O and 1.24% P_2O_5. As is well known, the most widely used catalyst by the biodiesel industry is potassium methylate, which is derived from imported KOH and methanol compounds, so it is expected that the K_2O reaction results from K_2CO_3 which is cheaper and dissolved in methanol produces potassium methylate which will function equally well in the RBDPO

Table 1. Composition of oxide compounds in K_2CO_3 XRF analysis results

Compound	Element Conc.	Units	Compound	Oxides Conc.	Units
Si	0.176	%	SiO_2	0.346	%
P	0.591	%	P_2O_5	1.24	%
K	97,089	%	K_2O	96,474	%
Ti	0.012	%	TiO_2	0.015	%
Mn	0	%	MnO	0	%
Co	0.016	%	Co_3O_4	0.015	%
Rb	0.023	%	Rb_2O	0.019	%
Aug	2	%	Ag_2O	1,806	%
Ba	0.018	%	BaO	0.016	%
Ce	0.01	%	CeO_2	0.01	%
Eu	0.04	%	Eu_2O_3	0.036	%
Er	0.025	%	Er_2O_3	0.022	%

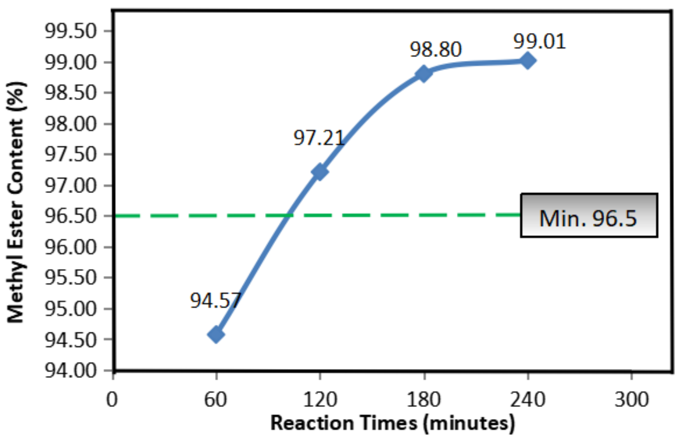


Figure 8. Effect of Reaction Times on Methyl Ester Content in Biodiesel

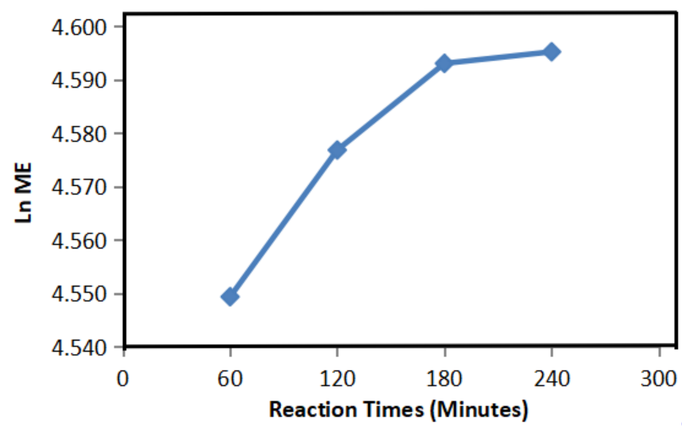


Figure 9. Relationship of Reaction Times with Ln ME for First Order Equations

transesterification reaction to biodiesel.

3.2 Effect of Reaction Time on K_2CO_3 Catalyst Performance

In Figure 6, it can be seen that when the reaction time is only 1 hour, the glycerol content in biodiesel is still quite large, namely 0.570%. At a reaction time of 120 minutes, the total glycerol content fell to 0.264%, but this figure still exceeded the maximum limit for biodiesel quality standards based on ASTM D 6584, namely 0.24% (w/w). The decrease in total glycerol content was very significant. The total glycerol content reached 0.124% for 180 minutes of reaction and 0.102% for 240 minutes of reaction. With a closed system (batch), the amount of 2% catalyst K_2CO_3 in the transesterification reaction for up to 240 minutes is still very active as described by Junior et al. (2019). Potassium carbonate is an inorganic compound consisting of potassium ions (K^+) and carbonate ions (CO_3^{2-}). This compound is generally in the form of a white crystalline powder and is soluble in water. K_2CO_3 is known to have the basic property of being a strong base, which means it can pick up protons from acid molecules and form new compounds.

The longer the reaction time, the total glycerol in biodiesel products will decrease, which means that the quality of biodiesel is getting better. Biodiesel products that meet International Standards, namely with a total glycerol value below 0.24%w are at reaction times of 180 minutes and 240 minutes. Meanwhile, the reaction times of 60 minutes and 120 minutes were still above the maximum limit set by the International Standard.

As for the value of Acid Number, all biodiesel products produce Acid Number values below the maximum limit based on ASTM D664 as shown in Figure 7. The maximum acid number for biodiesel must be no more than 0.8 mg KOH/g. High fuel acidity is linked with corrosion and deposit formation in engines.

Using a K_2CO_3 catalyst produces very good biodiesel quality when viewed from the high methyl ester content present in

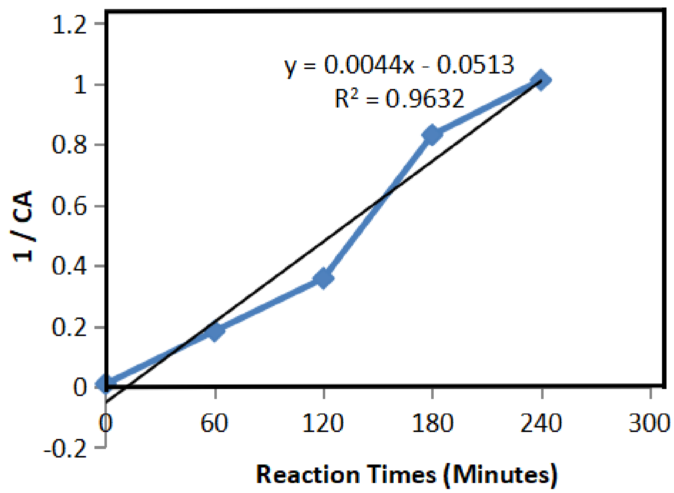


Figure 10. Relation of Reaction Times Witih 1/CA for Second Order Equations

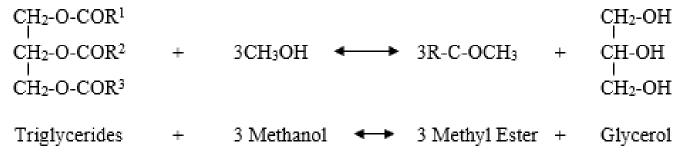
biodiesel, the longer the reaction time the greater the methyl ester content which can be achieved up to 99.01% (Figure 8). This shows that K_2CO_3 plays a very active role as a catalyst for biodiesel production. It is known that K_2CO_3 is an alkaline compound. Transesterification reactions with alkaline catalysts usually use alkali metal alkoxides such as NaOH, KOH, and $NaHCO_3$ as catalysts. This alkaline catalyst is more effective than the acid catalyst; the conversion results are better, the time required is shorter, and it can be carried out at room temperature. Tonetto and Marchetti (2010) tried 3 types of monolith catalysts, namely The Ca/Al_2O_3, Na/Al_2O_3 and K/Al_2O_3 as powder catalysts and reported a FAME (fatty acid methyl esters) formation of 94.7, 97.1, and 98.9% respectively after 6 hours of reaction. The present work shows that the use of monolithic catalysts K/Al_2O_3 in the transesterification of vegetable oils is a viable alternative.

The metal from the base is extracted into the alcohol which then reacts with the alcohol to form a nucleophilic alkoxide, where the alkoxide will attack the carbonyl group present in the raw material to produce a higher ester content. The minimum methyl ester content based on The European biodiesel specification, EN 14214, is specified at 96.5%. At the beginning of the reaction, the methyl ester content may still be low because the transesterification reaction takes time to reach equilibrium. As time goes by, the methyl ester content will increase proportionally with the increase in the conversion of reactants to products. This means that the longer the reaction time, the higher the level of methyl ester produced as shown in Figure 8.

3.3 Determination of Homogeneous Reaction Kinetics

3.3.1 Transesterification Process

The stoichiometry of the transesterification reaction of triglycerides into biodiesel known as methyl ester using a homogeneous catalyst is as in Equation (2) and the reaction rate can be shown in Equation (3).



$$A+3B \leftrightarrow 3C+D \quad (2)$$

$$-\Gamma = -\frac{dC_A}{d_t} = K_1 C_A^{\alpha} C_B^{\beta} - K_1 C_c^{\gamma} C_D^{\eta} \quad (3)$$

The stoichiometry of the reaction shows that the reaction above is reversible, but in this study, the methanol solvent was given in excess with the aim of a faster reaction rate with the conversion of reactants into larger products. So the reaction tends to move to the right (irreversible). So that Equation (2) can be written as in Equation (4) (Arita, 2009).

$$A + 3B \rightarrow 3C + D \quad (4)$$

Levenspiel (1998) stated that if one of the reactants is added in excess (excess) to the other reactants, the reactant can be ignored so that the reaction rate only depends on the reactant with the smallest mole. Then Equation (3) becomes a simple elementary reaction equation of order 1 (one) as in Equation (5).

$$-\Gamma_A = -\frac{dC_A}{d_t} = K_1 C_A^{\alpha} \quad (5)$$

Where :

Γ_A=biodiesel production reaction rate

α=reaction order

k_1=specific rate contant

Figure 7 previously shows that the % content of Methyl Ester (ME) in biodiesel is the same as the pure biodiesel product produced (as a function of reaction time). The integration results of Equation (5) are obtained ($C_{A_o}X_A$).

$$-\int_{CA_o}^{CA} \frac{dC_A}{C_A} = k \int_0^t \mathrm{dt}\ \ln \frac{CA_o}{CA} = ln(C_{AO} - C_A) = ln(ME) = Kt \quad (6)$$

From Equation (6) above, a graph is made between the methyl ester product (Ln ME) versus the reaction time t (min) which is used to prove whether the RBDPO transesterification reaction rate is first order as shown in Figure 9.

The resulting graph 9 turns out to form a curve, not a straight line, so the reaction rate is not first order. Then try with the assumption that the reaction is second order as shown by the following Equation (7).

$$-\Gamma_A = -\frac{dC_A}{d_t} = kC_A^2 \qquad -\int_{C_{A_o}}^{CA} \frac{dC_A}{C_A} = k\int_0^t \mathrm{dt}$$
$$\frac{1}{C_A} - \frac{1}{C_{A_0}} = kt \qquad \frac{1}{C_A} = kt + \frac{1}{C_{A_0}} \tag{7}$$

From Equation (7), a graph of 1/CA versus reaction time (minutes) is made as shown in Figure 10.

The results of Figure 10 shows a straight line with a Coefficient of determination by R^2 = 0.9632 from the empirical equation, the slope value (k) = 0.0044 with the intercept value (1/CA0) is (-0.0513), then the RBDPO transesterification reaction velocity equation into biodiesel are:

$$-\Gamma_A = -\frac{dC_A}{d_t} = KC_A^2 = 0.0044C_A^2 \tag{8}$$

4. CONCLUSION

Potassium methylate-based homogeneous catalyst K_2CO_3-methanol is proven to have a very high function in the transesterification reaction of RBDPO into biodiesel, this is evidenced by the acid content in biodiesel is only 0.12% and total glycerol is 0.124% in 3 hours reaction time, the percentage of catalyst is 2%w and methanol is 30%w by weight RBDPO, with methyl ester purity in biodiesel reaching 98.80%. Meanwhile, for the calculation of homogeneous reaction kinetics, a reaction rate equation is produced as in Equation (8), where the order of the RBDPO transesterification reaction is order 2 (second) and the reaction rate constant is 0.0044 $(\text{wt\% min})^{-1}$ and from the equation, straight line order 2 obtained intercept is (-0.0513) with R^2 = 0.9632. The results of this reaction kinetics are by the results of the reaction order found by (Darnoko and Cheryan, 2000).

5. ACKNOWLEDGMENT

The author would like to thank the Energy Engineering and Waste Management Laboratory of the Faculty of Engineering University of Sriwijaya and BPDPKS (Badan Pengelola Dana Perkebunan Sawit) for facilitating this research so that it can be completed properly.

REFERENCES

Arita, S. (2009). Proses Pembuatan Biodiesel di dalam Reaktor Unggun Diam (Fixed Bed Reactor) dengan Katalis Padat Alumina Berbasis Logam. *Proceedings of the 2009 National Fuel Cycle Seminar Serpong*, **13**; 1693–4687 (in Indonesia)

Cao, Y., H. A. Dhahad, H. Esmaeili, and M. Razavi (2022). MgO@Cnt@K_2CO_3 As a Superior Catalyst for Biodiesel Production from Waste Edible Oil Using Two-step Transesterification Process. *Process Safety and Environmental Protection*, **161**; 136–146

Chanakaewsomboon, I., K. Phoungthong, A. Palamanit, V. Seechamnanturakit, and C. K. Cheng (2021). Biodiesel Produced Using Potassium Methoxide Homogeneous Alkaline Catalyst: Effects of Various Factors on Soap Formation. *Biomass Conversion and Biorefinery*, **13**(10); 1–11

Darnoko, D. and M. Cheryan (2000). Kinetics of Palm Oil Transesterification in a Batch Reactor. *Journal of the American Oil Chemists' Society*, **77**; 1263–1267

Farobie, O. and Y. Matsumura (2017). State of the Art of Biodiesel Production under Supercritical Conditions. *Progress in Energy and Combustion Science*, **63**; 173–203

Fessenden, J. and S. Fessenden (1986). *Organic Chemistry Third Edition*. Jakarta: Erlangga

Foroutan, R., R. Mohammadi, J. Razeghi, and B. Ramavandi (2021). Biodiesel Production from Edible Oils Using Algal Biochar/CaO/K_2CO_3 As a Heterogeneous and Recyclable Catalyst. *Renewable Energy*, **168**; 1207–1216

Junior, E. G. S., O. R. Justo, V. H. Perez, F. da Silva Melo, I. Reyero, A. Serrano-Lotina, and F. J. Mompean (2020). Biodiesel Synthesis Using a Novel Monolithic Catalyst with Magnetic Properties (k2CO3/γ-Al2O3/sepiolite/γ-Fe2O3) by Ethanolic Route. *Fuel*, **271**; 117650

Junior, E. G. S., V. H. Perez, I. Reyero, A. Serrano Lotina, and O. R. Justo (2019). Biodiesel Production from Heterogeneous Catalysts Based K_2CO_3 Supported on Extruded γ-Al2O3. *Fuel*, **241**; 311–318

Knothe, G. and L. F. Razon (2017). Biodiesel Fuels. *Progress in Energy and Combustion Science*, **58**; 36–59

Kowthaman, C. (2020). Synthesis and Characterization of Carbon Nanotubes from Engine Soot and Its Application As an Additive in Schizochytrium Biodiesel Fuelled Dici Engine. *Energy Reports*, **6**; 2126–2139

Levenspiel, O. (1998). *Chemical Reaction Engineering. Third Edition*. John Wiley & Sons Publisher

Liu, H., L. Su, F. Liu, C. Li, and U. U. Solomon (2011). Cinder Supported K_2CO_3 as Catalyst for Biodiesel Production. *Applied Catalysis B: Environmental*, **106**(3-4); 550–558

Malins, K. (2018). The Potential of K_3PO_4, K_2CO_3, Na_3PO_4 and Na_2CO_3 as Reusable Alkaline Catalysts for Practical Application in Biodiesel Production. *Fuel Processing Technology*, **179**; 302–312

Munawar, A., R. Manurung, et al. (2020). Biodiesel Synthesis from Refined Bleached and Deodorized Palm Oil (RBDPO) by Transesterification Using Durian Shell Based Carbon Modified with Koh As Heterogeneous Catalyst. *IOP Conf. Series: Materials Science and Engineering*, **725**(1); 012063

Rodiah, S., D. Erviana, F. Rahman, and A. W. Budaya (2020). Modified CaO Catalyst from Golden Snail Shell (*Pomacea canaliculata*) for Transesterification Reaction of Used Cooking Oil. *Al-Kimia*, **8**(1)

Salmasi, M. Z., M. Kazemeini, and S. Sadjadi (2020). Transesterification of Sunflower Oil to Biodiesel Fuel Utilizing a Novel K_2CO_3/Talc Catalyst: Process Optimizations and Kinetics Investigations. *Industrial Crops and Products*, **156**; 112846

Sibarani, J., S. Khairi, Y. Yoeswono, K. Wijaya, and I. Tahir (2007). Effect of Palm Empty Bunch Ash on Transesterification of Palm Oil into Biodiesel. *Indonesian Journal of Chemistry*, **7**(3); 314–319

Taslim, Iriany, O. Bani, S. Parinduri, and P. Ningsih (2018). Biodiesel Production from Rice Bran Oil by Transesterification Using Heterogeneous Catalyst Natural Zeolite Modified with K_2CO_3. *IOP Conf. Series: Materials Science and Engineering*, **309**; 012107

Thinnakorn, K. and J. Tscheikuna (2014). Biodiesel Production Via Transesterification of Palm Olein Using Sodium Phosphate As a Heterogeneous Catalyst. *Applied Catalysis A: General*, **476**; 26–33

Tonetto, G. M. and J. M. Marchetti (2010). Transesterification of Soybean Oil Over Me/Al_2O_3 (Me= Na, Ba, Ca, and K) Catalysts and Monolith K/Al_2O_3-Cordierite. *Topics in Catalysis*, **53**; 755–762

Turnip, J. R., T. F. Tarigan, and M. S. Sinaga (2017). Pengaruh Massa Katalis dan Waktu Reaksi pada Pembuatan Biodiesel dari Limbah Minyak Jelantah dengan Menggunakan Katalis Heterogen K_2O dari Limbah Kulit Kakao. *Jurnal Teknik Kimia USU*, **6**(2); 24–29 (in Indonesia)

