

Effect of Temperature and Catalyst Concentration on the Quality of Biodiesel Oil Extracted From Black Soldier Fly Larvae (*Hermetia Illucens*)

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Abstract

Biodiesel is a renewable and environmentally friendly energy source that can be produced from lipid-rich materials through the transesterification process. Black soldier fly (BSF) larvae (*Hermetia Illucens*) contain approximately 30–40% fat, making them a potential alternative feedstock for biodiesel production. This study aimed to evaluate the effect of reaction temperature and KOH catalyst concentration on the yield and quality of biodiesel derived from BSF larvae oil. Oil extraction was conducted using the Soxhlet method with n-hexane, where 15 g of dried larvae powder extracted for 240 minutes produced the highest oil yield of 97% (w/w). The extracted oil was then converted into biodiesel through transesterification at two temperatures (65°C and 70°C) and two catalyst concentrations (1% and 2% w/v KOH). Biodiesel quality was analyzed based on SNI 7182:2015. The highest biodiesel yield, 60.19% (v/v), was obtained at 70°C and 1% KOH (A2B1). The resulting biodiesel met major SNI requirements, including density (869.59 kg/m³), kinematic viscosity (4.75 cSt), cetane number (44.25), acid number (0.32 mg KOH/g), iodine number (16.8 g-I₂/100 g), and FAME content (97.45%). These findings confirm that BSF larvae oil is a viable non-conventional feedstock for biodiesel production. This study is limited by the narrow range of reaction variables tested, suggesting that broader optimization—such as variations in alcohol ratio, reaction time, and pretreatment—may further improve yields. Practically, biodiesel production from BSF larvae supports waste valorization because larvae can be cultivated using organic waste streams. Socially, this approach reduces dependence on edible vegetable oils and supports circular economy initiatives. The originality of this research lies in its systematic evaluation of transesterification conditions for BSF-derived oil, providing new insights into the development of insect-based biodiesel technology.

Keywords: Biodiesel, Black Soldier Fly Larvae, n-Hexane, Soxhlet Extraction, Transesterification.

1. Introduction

Total energy consumption in Indonesia in 2019 increased by around 9.0% compared to 2018, which was 5,355,006 terajoules. Final energy consumption is the use of all fuel and energy by consumers for energy and non-energy uses that do not involve the transformation process (energy conversion) [1]. It is projected that energy consumption will continue to increase annually by 5.0% in the BaU (Business as Usual) scenario, 4.7% in the PB (Sustainable Development) scenario, and 4.3% in the RK (Low Carbon) scenario, so that in 2050 the energy demand for each scenario will reach 548.8 MTOE, 481.1 MTOE and 424.2 MTOE [2].

The government's strategic steps in meeting these energy needs are through exposure in press release 126.Pers/04/SJI/2021 which states that Indonesia must achieve a new renewable energy (NRE)

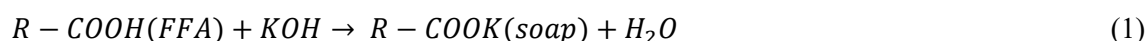
mix target of up to 23% in 2025 of total energy use, while in 2020 the EBT mix was only around 11.2% [3]. One thing that the government can do is develop alternative energy through the use of black soldier fly (BSF) larvae as raw materials for making biodiesel.

BSF larvae (*Hermetica Illucens*) are super fast waste decomposing agents that can decompose 60 kg of waste in just 12 days using 40,000 of 5-DOL (5-day-old BSF larvae) in an area of 1 m² [4]. The results of this organic waste decomposition will make BSF larvae have a fat content of up to 30-40%, this is considered higher when compared to the fat content in soybeans of 18% and palm oil of 30% [5]. The high fat content can be used as a raw material for making biodiesel. In addition, the use of animal fat will provide a higher cetane number when compared to vegetable oil [6] and reduce competition with food commodities, because vegetable oil is generally obtained from food ingredients [7].

Oil from BSF larvae can be extracted using the soxhlet extraction method and produces a yield of 18% with a content of lauric acid (C12:0) 43.13%, oleic acid (C18:1) 16.41%, myristic acid (14:0) 15.28%, palmitic acid (C16:0) 14.27%, and linolenic acid (C18:2) 3.61% and other fatty acids [8]. The use of petroleum ether as a solvent can increase the amount of BSF larvae extract oil yield to 56% [9]. The best solvent needed in the soxhlet extraction process is a solvent with the same polarity [10] and a low boiling point so that the extraction process will be more optimal. Oil extraction will be better if using a non-polar solvent that has the same polarity as the oil, one of which is n-hexane solvent [5], [8], [10].

BSF larvae extract oil is processed through a transesterification process using alcohol solvents and catalysts to form Fatty Acid Alkyl Ester (FAAE) or biodiesel. Alcohol solvents commonly used in the transesterification process are methanol, ethanol, n-propanol and some isopropanol. Ethanol will be better if used as a solvent for most of the fatty acids in the oil (caprylic acid C8:0, capric acid C10:0, myristic acid C14:0, palmitic acid C16:0, stearic acid C18:0) because it will produce biodiesel with a higher cetane number when compared to the use of other alcohols. While in the compounds of lauric acid (C12:0) and palmitoleic acid (C16:1) respectively, cetane numbers of 66.7 and 56.59 can be produced and kinematic viscosities of 2.43 cSt and 3.67 cSt with the use of methanol as a solvent. Processing of oil with oleic acid content (C18:1) will be better if using iso-propanol as a solvent, while linoleic acid (C18:2) and linolenic acid (C18:3) will be better if using n-butanol as a solvent [6].

The use of base catalysts in the transesterification process is considered more economical and can produce yields of up to 98% [11]. In addition, the use of base catalysts will not produce excessive acid numbers when biodiesel is produced. High acid numbers will cause corrosion in diesel engines, most of which are made of metal. KOH catalysts are able to produce higher levels of methyl esters when compared to the use of NaOH [12]. However, the use of base catalysts must also pay attention to the levels of free fatty acids (FFA) contained in vegetable and animal oils. This is because FFA is a carboxylic acid compound that can form soap compounds when bound to cations in base catalysts as in reaction Equation 1 [6].



FFA levels exceeding 2% will lead to saponification, which affects the emulsification process during biodiesel washing. Therefore, oil that has an FFA content of $\geq 2\%$ must first undergo an esterification process using alcohol and acid catalysts [6].

The concentration of the catalyst can affect the yield of biodiesel produced [13], because if the catalyst content is excessive it will become an impurity when biodiesel is produced, while the catalyst is lacking it will make the reaction more difficult or take longer. The transesterification temperature also affects the yield of biodiesel produced. Research conducted by Widyasanti, the optimum temperature of the transesterification process is 65°C [14]. The temperature used during the transesterification process must also take into account the boiling point of the solvent used, so that there is no reduction in the amount of alcohol/solvent when heated. In this study, observations were made on the effect of temperature and catalyst concentration on the yield produced and the quality of biodiesel based on SNI 7182:2015 concerning biodiesel quality [15].

Previous studies have demonstrated that Black Soldier Fly (BSF) larvae (*Hermetia illucens*) possess strong potential as a sustainable feedstock for biodiesel production due to their high lipid content and ability to bioconvert organic waste. Reported that BSF larvae can accumulate up to 30–40% lipid on a dry-weight basis while processing various organic substrates, highlighting their suitability for decentralized waste-to-energy systems [16]. Research on oil extraction techniques has shown that

solvent selection significantly influences oil yield. The most efficient solvent was discovered to be n-hexane, which under ideal circumstances outperformed petroleum ether by 1.3 % [17]. In terms of biodiesel production, Li et al., successfully converted BSF larvae oil into biodiesel using alkaline transesterification, achieving yields as high as 93% [18]. They also confirmed that the resulting biodiesel met key ASTM D6751 fuel quality parameters, including viscosity and cetane number, the free fatty acid (FFA) content in feedstock should be below 3% for efficient alkali-catalyzed transesterification using catalysts like KOH [19]. Further optimization of reaction conditions was conducted by Leong et al., who determined that temperatures around 65 °C with 1% KOH catalyst produced yields above 90%; however, temperatures exceeding methanol's boiling point reduced reaction efficiency due to methanol loss [20]. Collectively, these studies establish a strong scientific foundation for exploring parameter effects—such as temperature and catalyst concentration—on biodiesel yield and quality from BSF larvae oil.

Despite the existing research, there remains a significant gap: few studies have systematically examined how variations in transesterification temperature and catalyst concentration influence both the yield and quality of biodiesel derived specifically from BSF larvae oil, especially in the context of meeting national biodiesel standards (e.g., SNI 7182:2015). To achieve meaningful scale-up and practical application in Indonesia's push for renewables, these parameters must be optimized.

Accordingly, this study aims to analyze the effect of reaction temperature and KOH catalyst concentration on the yield and quality of biodiesel produced from BSF larvae oil. The specific objectives are: (1) To evaluate the impact of two transesterification temperatures (65 °C and 70 °C) on biodiesel yield and physicochemical properties, (2) To assess how two KOH catalyst concentrations (1% and 2% w/v) influence biodiesel production efficiency, and (3) To identify the optimal temperature–catalyst combination which maximizes biodiesel yield while ensuring compliance with SNI 7182:2015 quality standards. By investigating these parameters, this work seeks to contribute to the growing field of insect-based biofuels — offering an alternative route for renewable energy that helps close the gap between Indonesia's rising energy demand and the slow uptake of renewable energy resources.

2. Method

The BSF larvae used are larvae aged 17-21 days from hatching or 12-16 days since the provision of food nutrition from waste (because the age of the larvae used to degrade waste is 5-DOL/5-Days Old Larvae). This phase is used because the larvae have reached maximum weight [2] with the characteristics of brownish white larvae. The larvae are dried under the hot sun for 3-5 days for 6 hours (09:00-15:00). The dried larvae are ground using a blender until the BSF larvae flour is obtained according to the desired size, Figure 1.



Figure 1. Dry BSF Larvae and BSF Larvae Flour

BSF larvae oil extraction using a soxhlet extractor with n-hexane solvent. BSF larvae flour to be extracted is taken as much as 15 grams and wrapped in filter paper and tied with raffia rope so that solids are not included during the extraction process. This soxhlet extraction is carried out using 2 sizes of

extraction chambers/lead pipes, one large 500 mL and another small 250 mL. The large soxhlet can be filled with more samples and n-hexane solvent up to 225 mL, while the small extraction tube can only be filled with less sample and solvent up to 150 mL. The extraction process is carried out by heating from a hot plate at a temperature of 69-75 ° C (according to the boiling point of n-hexane which is 69 ° C) [21], [22]. The extraction process is carried out in several cycles. The extraction process is stopped when the color of the n-hexane solution has returned to colorless (clear/transparent) which means that the oil has been completely extracted, Figure 2.



Figure 2. The Making of Sample Wraps and Soxhlet Extraction of BSF Larvae Oil

The yield of oil produced can be calculated using the Equation 2:

$$Yields = \frac{BSF\ oil\ weight\ (g)}{BSF\ flour\ weight\ (g)} \times 100\% \tag{2}$$

The oil from the extraction process was analyzed for its free fatty acid content using the ASTM D5555-95 standard (reapproved 2011) on Free Fatty Acid Content Tests in Animal, Marine, and Vegetable Oils and Fats using Fat Liquors and Filling Compounds [23] and the AOCS Official Method Ca 5a-40 standard (reapproved 2009) on FFA [24]. The FFA content was calculated using the Equation 3.

$$FFA\ (\%) = \frac{V_{KOH} \times N_{KOH} \times MW_{oil}}{1000 \times W_{oil}} \times 100\% \tag{3}$$

Note:

- V_{KOH} : KOH volume (mL)
- N_{KOH} : KOH normality (N)
- MW_{oil} : Molecular Weight of oil sample (g/mol)
- W_{oil} : Oil sample wight (g)

The FFA content of BSF larvae oil in this study was 1.33% (FFA <2%) so that the biodiesel production process was continued to the transesterification process. The biodiesel production process is carried out by reacting BSF larvae oil and methanol with a molar ratio of oil with alcohol was 1:8. The transesterification process uses a commercial base catalyst, namely KOH pro analysis. Based on the Completely Randomized Design (CRD) experiment, there are 2 factors, namely temperature (A) and

catalyst concentration treatment (B) and 2 levels, namely temperature variation (A1) 65°C and (A2) 70°C and catalyst concentration variation (B1) 1% and (B2) 2% w/v so that there are 4 types of samples with each being repeated 2 times, [Table 1](#).

[Table 1](#). Sample Naming

Temperature	Catalyst Concentration	
	1% (B1)	2% (B2)
65°C (A1)	A1B1	A1B2
70°C (A2)	A2B1	A2B2

The BSF larvae oil used for each sample was 30 mL and heated on a hotplate until it reached the treatment temperature of 65°C (sample A1) and 70°C (sample A2), the temperature was observed with a thermometer. The transesterification process was calculated when the sample had reached the observation temperature and a methoxide solution (a mixture of alcohol and base catalyst) had been added. The methoxide solution was made by mixing 52.82 ≈ 60 mL of methanol with 0.3 grams (sample B1) and 0.6 grams (sample B2) of KOH pro analysis. The transesterification process was carried out by stirring at 700 rpm for 1 hour. The results of the transesterification process were transferred to a separating funnel and left overnight so that it would produce biodiesel in the upper layer and glycerol at the bottom and impurities in the form of catalyst residue, excess alcohol residue, and salt/soap. The glycerol layer and other impurities at the bottom were removed by opening the separating funnel tap.

The obtained biodiesel was purified by washing with warm water (± 65-70°C) for 3 repetitions. The yield of biodiesel produced from each was calculated using Equation 4.

$$Yield = \frac{Biodiesel\ volume\ (mL)}{BSF\ oil\ volume\ (mL)} \times 100\% \tag{4}$$

The highest oil yield was analyzed for quality using the SNI 7182: 2015 standard on biodiesel. The biodiesel quality parameters tested were density, kinematic viscosity, cetane number, acid number, iodine number, and Fatty Acid Methyl Ester (FAME) content, [Table 2](#).

[Table 2](#). Biodiesel Quality Requirements According to SNI 7182:2015

Parameter	Unit	Requirements
Density at 40°C	kg/m ³	850-890
Kinematic viscosity at 40°C	mm ² /s (cSt)	2.3-6.0
Cetane number	Min	51
Acid number	mgKOH/g, max	0.5
Methyl ester content	%massa, min	96.5
Iodine value	%massa (g-I ₂ /100g), maks	115

Source: SNI 7182:2015 [7]

3. Result and Discussion

3.1 BSF Larvae Oil Extraction

The soxhlet extraction process carried out to extract BSF larvae oil showed highly heterogenous results in terms of the oil yield produced, the complete results of BSF oil extraction can be seen in [Table 3](#).

[Table 3](#). BSF Larvae Oil Extraction Results

Larval Flour Weight (g)	Extraction Time (Minute)	Number of Cycles	n-Hexane Volume (mL)	Yields (%)
9	120	8	225	51
9	240	15	225	57
15	120	15	225	75
15	240	20	225	97

Larval Flour Weight (g)	Extraction Time (Minute)	Number of Cycles	n-Hexane Volume (mL)	Yields (%)
20	120	17	225	55
20	240	20	225	65
25	120	30	225	67
25	240	40	225	87
30	120	36	225	33
30	240	32	225	58

The extraction of oil from Black Soldier Fly (BSF) larvae using the Soxhlet method with n-hexane as a solvent has shown significant variations in yield depending on extraction parameters such as extraction time, larval flour weight, and the number of cycles. The data indicate that longer extraction times generally result in higher oil yields, with a notable increase observed when extending the duration from 120 minutes to 240 minutes. For instance, using 15 g of larval flour, the oil yield increased from 75% to 97% when the extraction time was doubled. This suggests that prolonged solvent exposure enhances oil solubilization and diffusion, though diminishing returns are observed beyond a certain duration. Additionally, the number of extraction cycles influenced oil recovery, with higher cycles leading to increased yields. However, at high sample weights, even increasing the number of cycles did not significantly improve oil extraction, likely due to mass transfer limitations. These findings are consistent with research which demonstrated that optimizing solvent-to-solid ratios and extraction durations significantly enhances the recovery of oils [25].

The weight of larval flour also plays a critical role in extraction efficiency. The highest oil yield (97%) was obtained using 15 g of flour, whereas both lower and higher flour weights resulted in reduced yields. Notably, when 30 g of flour was used, the yield was significantly lower (33% at 120 minutes and 58% at 240 minutes), indicating that excessive sample weight may hinder solvent penetration and reduce extraction efficiency. This trend aligns with findings were reported that excessive sample loading could limit mass transfer efficiency, reducing overall oil recovery in Soxhlet extraction [26]. Moreover, research suggests that while Soxhlet extraction is effective, ultrasound-assisted extraction (UAE) can yield comparable or higher oil recovery with reduced solvent consumption and shorter extraction times, highlighting the need for greener alternatives [27].

Furthermore, Soxhlet extraction using n-hexane remains a viable method for BSF oil recovery, particularly in biodiesel production, where high oil yield is crucial [5]. A study demonstrated that Soxhlet extraction of BSF larvae achieved yields up to 97%, supporting its potential for industrial applications. However, due to high solvent usage and environmental concerns, alternative extraction techniques such as ultrasonic-assisted or aqueous enzymatic extraction may enhance efficiency while reducing solvent dependency. The use of ultrasound-assisted extraction, in particular, has been found to increase oil recovery by up to 15% compared to Soxhlet extraction, making it a promising alternative for sustainable BSF oil production. Given these observations, optimizing extraction parameters, such as maintaining an appropriate flour weight (15–20 g) and extraction duration (approximately 240 minutes), is crucial for maximizing yield while considering sustainable extraction practices.

3.2 Transesterification of BSF Oil

The yield results for each treatment were analyzed using Complete Random Design (CRD) analysis. The analysis was carried out using 2 factors, namely the catalyst concentration and the reaction temperature used. The existing variations were reacted together with 2 repetitions. Biodiesel yield data are presented in Table 4.

Table 4. Biodiesel Yield

Sample	Repetition		Average
	1	2	
A1B1	57.01	52.11	54.56
A1B2	45.70	46.40	46.05
A2B1	60.50	59.88	60.19

A2B2	52.61	54.98	53.79
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The yield produced from the transesterification process with variations in catalyst and temperature ranged from 45.7-60.19%. The highest yield was produced in sample A2B1 (temperature 70°C and catalyst 1%). The results of the CRA data were then further tested using ANOVA (analysis of variance) to determine the best treatment in each sample. The results of the ANOVA test are presented in Table 5.

Table 5. ANOVA Test Results

Source	df	SS	MS	F _{count}	F _{table}		Notation
					5%	1%	
A	1	89.44	89.44	23.45	7.71	21.19	**
B	1	111.09	111.09	29.13	7.71	21.19	**
AB	1	2.24	2.24	0.59	7.71	21.19	NS
Error	4	15.26	3.81				
Sum	7	218.02					

Note: ** significantly different, ^{NS}not significant

The results of the ANOVA statistical analysis with a test level of 95% and 99% showed that the interaction factor against both variations produced $F_{count} < F_{table}$ at both test levels, this means that the interaction of the two variations in each sample did not have a significant difference. In contrast to the test results for factor A (temperature variation) and factor B (catalyst variation) showed significantly significant different results because $F_{count} > F_{table}$ at both test levels. The results of the ANOVA test for factors A and B were continued in further tests using DMRT (Duncan Multiple Range Test) to determine which variation of the two factors had the best results.

The DMRT test for Factor A (temperature) indicated that A2 (70°C) was the optimal temperature. Different from the DMRT test for factor B which shows code B1, namely catalyst concentration variation of 1% is the best catalyst variation factor. Based on these results, the combination of variations A2B1 has the best combination that produces the highest yield. The graph of interaction data between variations is presented in Figure 3.

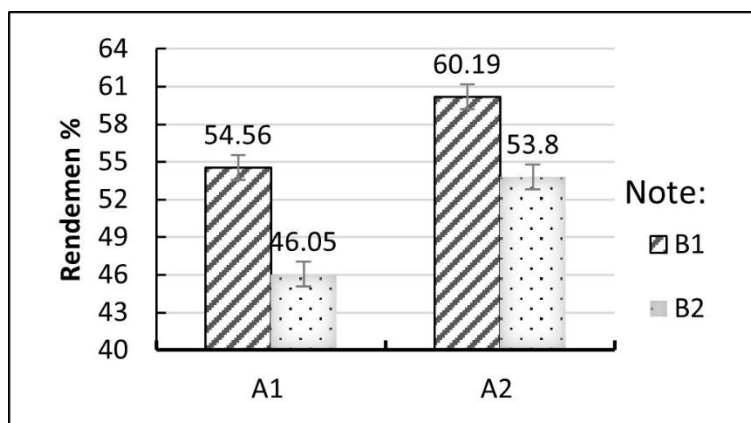


Figure 3. Data of Interaction between Variations A and B

The results of the study showed that the higher the reaction temperature, the higher the yield, this is because the collisions that occur in the reaction increase. The temperature used in the reaction will increase the viscosity of the oil so that the molecular movement moves faster. The faster the molecular movement, the more collisions between the reactant molecules increase. Based on the data, the addition of a 2% catalyst concentration produces a lower yield compared to samples with a 1% catalyst concentration. Based on the theory, increasing the catalyst concentration will accelerate the reaction rate because the catalyst can lower the activation energy of the reaction so that the products produced by the reaction increase [28]. The addition of excessive catalyst concentration in a reaction can also result in a soap formation reaction [29]. This statement is supported by the difficulty of washing in sample A1B2.

The difficulty of washing is thought to be due to the formation of soap in the sample. The formation of soap results in a lower mass of biodiesel produced, because the fat is converted into soap.

3.3 Quality of BSF Biodiesel

Biodiesel characterization was carried out by testing the biodiesel sample that had the highest yield, namely sample A2B1. The A2B1 sample test included several parameters. SNI 7182:2015 biodiesel parameter data and BSF larvae biodiesel test results are presented in Table 6.

Table 6. Characteristics of BSF Larvae Biodiesel

No.	Parameter	Unit	SNI 7128:2015	Biodiesel of BSF Larvae	Note
1.	Density at 20°C	Kg/m ³	850-890	869,59	A
2.	Kinematic viscosity at 40°C	mm ² /s (cSt)	2,3 - 6,0	4,27	A
3.	Cetane number	-	min 51	44,25	B
4.	Acid number	mg-KOH/g	0,5	0,32	A
5.	Iodine value	g-I/100 g	maks 115	16,8	A
6.	Methyl ester content	%massa	min 96,5	97,45	A

Note: ^Asatisfy the SNI Criteria, ^Bnot satisfy the SNI Criteria.

3.3.1 Density at 40°C

Density is measured using the AOAC 920.212 and 920.213 methods to calculated specific gravity using a pycnometer [30]. Through testing and calculating the density value of BSF larvae biodiesel of 869.59 kg/m³, this value has met the SNI standard. The density value of oil before transesterification has a high value compared to the density value of oil (biodiesel) after transesterification. The density values of oil can be caused by the content of impurities in the oil [31], in biodiesel the content of impurities such as glycerol has been removed in washing the biodiesel.

3.3.2 Kinematic Viscosity at 40°C

Kinematic viscosity is measured in laboratoium pangan, politeknik negeri jember used ASTM D445-06 standard test method for kinematic viscosity of transparent and opaque liquid (and calculation of dynamic viscosity) [32]. The viscosity value affects combustion in the engine combustion chamber. Fuel with low viscosity will be easily injected, atomized and mixed with air so that the fuel is easily burned and perfect combustion occurs. A high viscosity value can result in heavier injection pump performance and difficulty in atomizing the fuel. Difficulty in atomizing can cause incomplete combustion. Incomplete combustion will leave combustion residue (dirt) which if it continues will damage the combustion chamber [33]. The viscosity value of the fuel has been limited in SNI 7128: 2015. The kinematic viscosity value of BSF larvae biodiesel at a temperature of 40°C is 4.27 and has met the established standards.

3.3.3 Cetane Number

The cetane number is related to the ignition quality of the fuel. A high cetane number indicates that the fuel is flammable at lower temperatures. Fuel that is flammable at low temperatures can reduce the occurrence of detonation [34]. Detonation is an explosion event in the combustion chamber that occurs during the combustion process. If detonation occurs continuously, it will cause damage to the engine.

The cetane number value is obtained from calculations using an approximation formula as carried out in the study by Krisnangkura [35] and the constant values a, b and c are obtained from the calculation of substitution and elimination of 3 animal oil biodiesel characteristic data. Animal oil biodiesel data used to determine the constants a, b and c are obtained from chicken fat data [36], dairy cow fat and beef fat [37].

Through the calculation of the cetane number approach (layer 3), the estimated cetane value of BSF larvae oil is 44.24 and this value has not met the standards set by SNI 7128:2015. The low cetane

number value can be caused by the low content of hexadecane hydrocarbons in the fatty acid methyl ester and also the low cetane number value in this study is suspected because the test only uses an approximation formula.

3.3.4 Acid Number

Acid number was measured using AOCS Ca 5a-40 standard [24]. The acid number value identifies the free fatty acids contained in biodiesel. High acid number values can increase the corrosiveness of the fuel. Acid numbers can cause deposits in the combustion chamber because ash is formed during the combustion process [38]. If deposits in the combustion chamber are allowed to accumulate, they will affect the combustion process and reduce engine performance. The acid number value of BSF larvae biodiesel is 0.32 and has met the standards set in SNI 7128:2015.

3.3.5 Iodine Number

The iodine value was tested at the Laboratorium Pangan, Politeknik Negeri Jember using the AOCS Tg 1-64 standard [39]. The iodine number is a number that indicates the level of unsaturation of biodiesel or the number of double bonds of fatty acids that make up biodiesel. The more unsaturated the fatty acid content of biodiesel, the easier the combustion process will be, because unsaturated fatty acids easily react with oxygen. Bonds in fatty acids are more susceptible to polymerization reactions that occurs will increase the viscosity of the fuel. Iodine numbers that are too high can cause crust to form in the combustion chamber [31]. Testing the iodine number value of BSF larvae biodiesel is 16.8 and is in accordance with the standards set in SNI 7128: 2015.

3.3.6 Methyl Ester Content

FAME (Fatty Acid Methyl Ester) content is a content that indicates the value of methyl ester content in the fuel. The higher the FAME content, the better the quality of the fuel. FAME content in fuel can affect fuel consumption and reduce combustion emissions, because combustion in the combustion chamber occurs more perfectly [40]. The FAME content value of BSF larvae biodiesel is 97.45. This value has met the standards set in SNI 7128:2015.

4. Conclusion

The best soxhlet extraction process is to use a total of 15 grams of BSF larvae flour divided into 3 grams each in 1 wrap (a total of 5 wraps). The n-hexane solvent used was 225 mL in a 500 mL extraction chamber, with 20 extraction cycles for 240 minutes, capable of producing an oil yield of 97% or 14.6 grams with oil density, $\rho_{oil} = 0.9125$ g/mL. Based on the Analysis of Variance (ANOVA) test, it shows that parameter A (catalyst concentration) and parameter B (temperature) show $F_{count} > F_{table}$ 1% and 5%, so that the treatment shows significantly different. While the interaction of treatments A and B was not significantly different ($F_{count} < F_{table}$ 1%). The highest biodiesel yield was produced in reactor A2B1 where the biodiesel produced reached 60.19% or 18.06 mL with a cetane number quality of 44.25, and a density of 869.59 kg/m³, kinematic viscosity of 4.27 cSt, acid number 0.32 mg-KOH/g, iodine value 16.8 g-I₂/100g which has met the biodiesel quality standards based on SNI 7182: 2015. Further research on biodiesel from BSF larvae oil is expected to be able to test the cetane number directly.

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