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EFFECT OF OPERATING TEMPERATURE ON BIODIESEL PRODUCTION FROM PALM FATTY ACID DISTILLATE BY USING THE AMBERLYST CATALYST

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ABSTRACT

The purpose of this study is to determine the effect of operating temperatures on biodiesel production from Palm Fatty Acid Distillate (PFAD) by using Amberlyst DPT 2 UPS catalyst. Amberlyst DPT 2 UPS catalyst is a heterogeneous catalyst whose performance is strongly influenced by operating temperature. In this study, Amberlyst DPT 2 UPS catalyzes the reaction between PFAD and methanol. The molar ratio of PFAD to methanol is 1: 5, and the reaction time is 8 hours. Operating temperature variations performed are 120 °C, 125 °C, 130 °C, and 135 °C. Analysis carried out in the study included analysis of acid value, flash point, kinematic viscosity, density, and composition of biodiesel. The acid value, the flash point, the kinematic viscosity, the density, and the biodiesel composition is analyzed by the ASTM Standards. The results showed that the highest conversion of 99.85% is obtained at an operating temperature of 130 °C, while the analysis results of acid values, flash points, kinematic viscosity, and densities have met the ASTM standard for all variations in operating temperature.

Keywords: palm fatty acid distillate, PFAD, amberlyst DPT 2 UPS, palm oil, biodiesel.

INTRODUCTION

Indonesia is an archipelago with a tropical climate that allows for the growth of a wide variety of plants. One of Indonesia's primary commodities of plantation products is palm oil, and currently, Indonesia is the largest palm oil-producing country in the world. This makes Indonesia very potential to develop renewable energy based on palm oil. One of the energy products that can be produced from palm oil is biodiesel.

Biodiesel can be produced from a variety of oils, but the barrier is how to obtain raw materials sustainably because of limited production. Table-1 shows the oil that has been used in the process of making biodiesel, both from edible oil sources and non-edible oil sources.

In the biodiesel production from vegetable oils, the main problem is the operating temperature. The operating temperature will affect the properties of biodiesel formed, such as acid value, flash point, kinematic viscosity, and density of biodiesel. In this research, the raw material used is palm fatty acid distillate (PFAD) which is reacted with methanol using a heterogeneous catalyst. Heterogeneous catalysts are solid catalysts, which will not dissolve with oil or reactants. Heterogeneous catalysts are preferred because they have advantages in terms of purification and the ability to be reused. Heterogeneous catalysts can also be grouped into two parts, namely heterogeneous acid catalysts and heterogeneous base catalysts. Some heterogeneous catalysts that have been used in biodiesel production can be seen in Table-2.

In this research, the catalyst used is the Amberlyst catalyst. This catalyst is one type of ion exchange resin catalyst with a high catalytic activity that can catalyze oil and fatty acids into biodiesel [1–4]. The reaction that occurred in this research is esterification, where PFAD would react with methanol to form methyl ester and water by using Amberlyst as a catalyst. The reactions that occur are as follows:

$$\underset{\text{PFAD}}{\mathrm{RCOOH}} + \underset{\text{Methanol}}{\mathrm{CH_3OH}} \xleftrightarrow{\text{catalyst}} \underset{\text{Methyl Esters}}{\mathrm{RCOOR}} + \underset{\text{Water}}{\mathrm{H_2O}}$$

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Table-1. Several oil sources are used to produce biodiesel [5, 6].

Oil type	Source	Oil produced (%)
Edible	Palm oil	30-60
	Coconut	63-65
	Soy	15-20
	Sunflower	25-35
	Peanuts	45-55
	Rapeseed oil	38-46
Not edible	Jatropha curcas	35-40
	Castor	53
Another source	Neem oil	20-30
	Pongamia pinata	27-39
	Rubber seed	40-50
	Sea mango oil	54
	Cotton seed	18-25
	Algae micro	30-70

Table-2. The heterogeneous catalysts in biodiesel production.

Catalyst	Raw material	Yield
K_2CO_3/MgO [7]	soybean	99.5%
CaO [8]	sunflower	80%
CaO/Al_2O_3 [9]	palm oil	98.64%
Volcanic ash [10]	waste cooking oil	99.58%
Solid Vanadium Phosphate [11]	soybean	80%
Mg-Al hydrotalcite [12]	jatropha curcas	95.2%
Na/BaO [13]	canola	97.5%
ZnO [14]	castor	91%
ZS/Si [15]	waste cooking oil	98%
Mg/Zr [16]	sunflower	99.5%
Amberlyst 15 [3]	oleic acid	87%
Amberlyst 46 [2]	oleic acid	98.6%

MATERIALS AND METHODS

The raw materials used in this study are PFAD, methanol, and Amberlyst DPT 2 UPS catalyst. Table-3 shows the characteristics of the PFAD. The component of PFAD consists of saturated and unsaturated fatty acids, and the component majority consists of palmitic acid (C_{16}) and oleic acid ($C_{18:1}$), while the initial acid value is 253 mg KOH/g.

Esterification from PFAD

In this study, PFAD is fed from the top of the reactor with a temperature variation of 120 °C, 125 °C, 130 °C, and 135 °C, where previously the Amberlyst catalyst was put into the reactor. The reactor operating pressure is 1 atm. After that, methanol is flowed from under the reactor in vapor conditions at a temperature of 160 °C. The molar ratio of methanol and PFAD is 5:1. Sampling is done every 8 hours for each temperature.

Product Analysis

The acid value, the flash point, the kinematic viscosity, the density, and the biodiesel composition is analyzed by the ASTM (American Society for Testing and Material) Standards. Acid values are analyzed using the AOCS Te 2a64 titration method using a KOH solution in ethanol. Flash points are analyzed by the ASTM D93 method using the Pensky-Martens flash point tester (Petrotest PMA-4). Kinematic viscosity is tested by the ASTM D445 method using Canon-Fenske opaque viscometer. Density is analyzed by the ASTM D1298 method using the Hydrometer Method, while the conversion of PFAD into biodiesel is determined by using Equation (1), where the free fatty acid removal shows the amount of PFAD converted into biodiesel [1]. The biodiesel compositions are analyzed using gas chromatography.

$$Free\ fatty\ acid\ removal\ (\%) = \frac{Initial\ acid\ value - Final\ acid\ value}{Initial\ acid\ value} x100 \qquad (1)$$

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Table-3. Characteristics of the PFAD.

Properties	Measurement results	Unit	Test Method
Colour	3.5R	5¼ in Lovibond	AOCS Cc 13e-92
	31.0Y	5¼ in Lovibond	AOCS Cc 13e-92
Acid Value	253	mg KOH/g	AOCS Te 2a-64
Iodine Value	253	g I_2/100 g	AOCS TI 2a-64
C_{10} (capric acid)	0.1	%	ASTM D6584
C_{12} (lauric acid)	1.4	%	ASTM D6584
C_{14} (myristic acid)	1.9	%	ASTM D6584
C_{16} (palmitic acid)	31.3	%	ASTM D6584
C_{18} (stearic acid)	12.3	%	ASTM D6584
$C_{18:1}$ (oleic acid)	42.3	%	ASTM D6584
$C_{18:2}$ (linoleic acid)	6.8	%	ASTM D6584
C_{20} (arachidic acid)	1.0	%	ASTM D6584
Water content	0.04	%	ASTM D2705

RESULTS AND DISCUSSIONS

Effect of Reaction Temperature on Acid Values

In general, the higher the temperature, the greater the conversion of reactions produced [2, 17]. This is acceptable because the esterification reaction is endothermic, but this did not happen in this study. Figure-1 shows the effect of temperature on acid values of biodiesel. The results show that the reaction conversion at 130 °C is higher than at 135 °C. The reaction conversion at 130 °C becomes the highest conversion peak, 0.36 mg KOH/g and decreases to 0.37 mg KOH/g at 135 °C. This is caused by the effectiveness of the catalyst, which has reached its optimal catalytic level so that the increase in temperature no longer affects the reaction conversion, and the results obtained are not much different between the two temperatures.

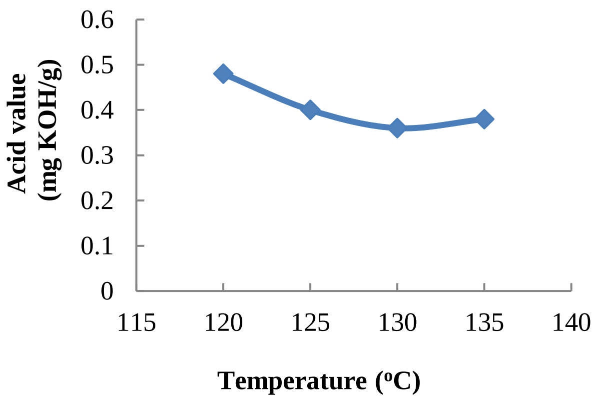

Figure-1. Effect of reaction temperature on acid values.

Effect of Reaction Temperature on Flash Point

Flash point is the lowest temperature where fuel will ignite when exposed to sparks, and then it will burn out again quickly. Based on ASTM standards, the flash point must be ≥130 °C [5, 18]. In this study, the higher the temperature, the higher the flash point produced. This is because the methanol content in biodiesel is very few. Methanol has a flash point of 11 °C, so the higher the methanol content, the flash point of biodiesel will be lower. At an operating temperature of 120 °C, the obtained flash point is 139 °C, and at an operating temperature of 135 °C, the flash point obtained is 205 °C. The effect of reaction temperature on flash point of biodiesel can be seen in Figure-2.

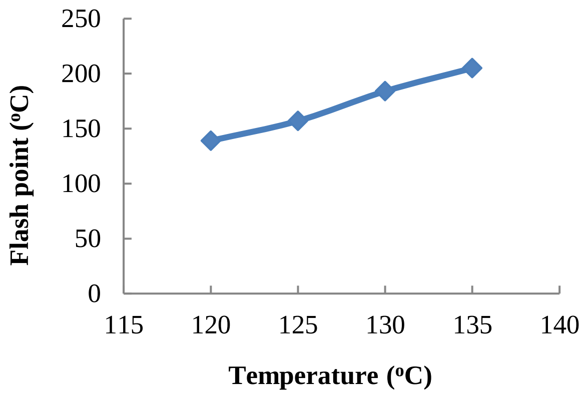

Figure-2. Effect of reaction temperature on flash points.

Effect of Reaction Temperature on Kinematic Viscosity

Kinematic viscosity is the ratio between absolute viscosity and density. The viscosity of biodiesel produced based on ASTM standards must range from 1.9 mm^2/s to 6 mm^2/s [5]. High viscosity values affect fuel atomization and air that is not good, so that combustion becomes imperfect. In this study, the viscosity value that meets ASTM

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standards is obtained because the viscosity produced ranged from 4.29 mm^2/s - 4.42 mm^2/s. The effect of reaction temperature on kinematic viscosity of biodiesel can be seen in Figure-3.

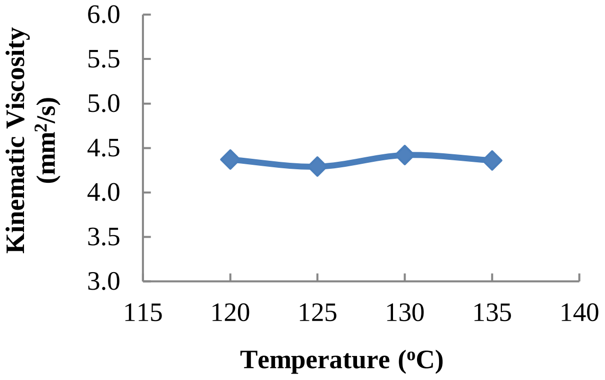

Figure-3. Effect of reaction temperature on kinematic viscosity.

Effect of Reaction Temperature on Density

Density is an important parameter in a product, especially trade that uses volume as a measurement basis. The biodiesel density has been standardized with ASTM D1298 method, which is 860 kg/m^3 - 900 kg/m^3 [5, 6]. In this study, the density obtained results that meet ASTM D1298 standards, where the density obtained is 0.869 kg/m^3 - 0.880 kg/m^3. The effect of reaction temperature on density of biodiesel can be seen in Figure-4.

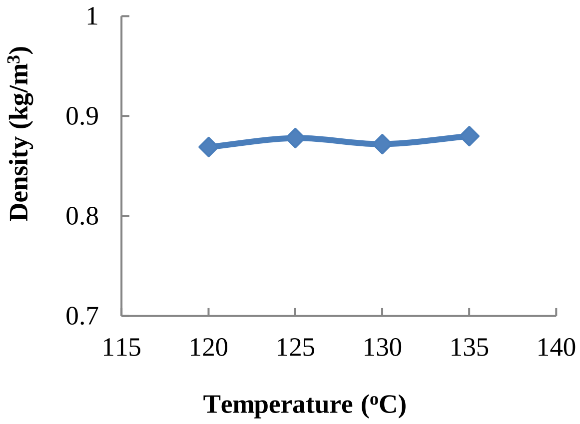

Figure-4. Effect of reaction temperature on density.

Effect of Reaction Temperature on Biodiesel Yield

The FAME conversion is the number of fatty acids that are converted to biodiesel. The FAME conversion is calculated by using Equation (1). The results obtained by this equation mean that the lower the acid value, the greater the fatty acids that are converted to biodiesel so that the biodiesel yield obtained is also greater. This study also obtained the higher the temperature, the smaller the acid value obtained. Figure-5 shows that all temperatures gave comparable yield, between 99.81% to 99.85%.

In principle, acid values are a measure of the amount of free fatty acids and are calculated based on the molecular weight of fatty acids or fatty acid mixtures. The determination of acid values is used to measure the number of fatty acids involved in oil.

This research focuses on acid value as a very important test parameter in determining biodiesel because, in this study, fatty acids are used as raw materials. This is different if triglycerides are used as raw materials.

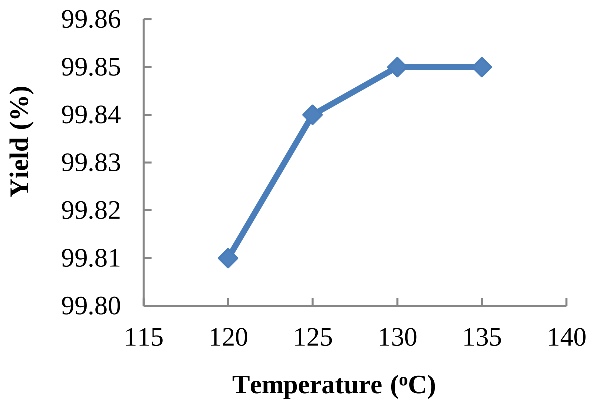

Figure-5. Effect of reaction temperature on biodiesel yield.

The Composition of Biodiesel

Table-4 shows the biodiesel composition, which is analyzed by using gas chromatography for various reaction temperatures. This table shows that C_{16} and $C_{18:1}$ dominate the results at all reaction temperature, and the biodiesel composition consists of C_{10} to C_{20}. Based on the results obtained, it is known that the composition of the highest biodiesel component for each operating temperature is different. These results provide essential information to use the operating temperature in biodiesel production to maximize the yield of the required components.

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Table-4. The Composition of biodiesel by using gas chromatography analysis.

Composition	Temperature			
	120 °C (%)	125 °C (%)	130 °C (%)	135 °C (%)
C_{10}	0.06	0.30	0.06	0.05
C_{12}	1.54	2.05	1.44	1.50
C_{14}	2.73	3.15	2.61	3.45
C_{16}	37.12	34.08	36.24	30.91
C_{18}	14.44	16.13	14.62	18.09
$C_{18:1}$	34.42	34.23	34.77	35.60
$C_{18:2}$	5.50	5.17	5.49	5.22
C_{20}	0.98	1.09	1.18	1.48

CONCLUSIONS

Operating temperature affects the Amberlyst DPT 2 UPS catalyst performance in producing biodiesel from Palm Fatty Acid Distillate (PFAD). The highest conversion obtained is 99.85% at an operating temperature of 130 °C. The analysis showed that the acid values are around 0.36 mg KOH/g - 0.48 mg KOH/g, flash points ranged from 139 °C - 205 °C, kinematic viscosity ranged from 4.29 mm^2/s - 4.42 mm^2/s, and densities ranged from 0.869 kg/m^3 - 0.880 kg/m^3. At all reaction temperature variations, 120 °C, 125 °C, 130 °C, and 135 °C, all the analysis results of acid values, flash points, kinematic viscosity, and density have met ASTM standards.

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