Int. J. Renew. Energy Dev. 2023, 12(4), 760-767

Contents list available at IJRED website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.undip.ac.id

Research Articles

Comparative analysis of filterability behavior of B30 and B40 biodiesel blends on various porosity and dimension of fuel filter

Yogi Pramudito[a,b*], Nur Allif Fathurrahman[b], Ahmad Syihan Auzani[a], Cahyo Setyo Wibowo[b], Riesta Anggarani[b], Ariana Soemanto[b], Bambang Sugiarto[a]

[a]*Department of Mechanical Engineering, Universitas Indonesia, 16424 Depok, West Java, Indonesia.*

[b]*Department of Product Application Technology, Research and Development Centre for Oil and Gas Technology (LEMIGAS), 12230 South Jakarta, Indonesia*

Abstract. This report is focused on comparative analysis of the impact of using biodiesel blends containing more than 30% biodiesel in diesel engine filtration systems. The objective of this study is to support the sustainability of the mandatory biodiesel utilization program by more than 30%. To evaluate filterability behavior of high-percentage biodiesel blends, namely B30 and B40 (30 and 40%-vol biodiesel on diesel fuel), the study employed the ASTM D 2068 Filter Blocking Tendency (FBT). After filter rig test, fuel filter pressure was also evaluated using the JIS 1617 standard method. It is important to note that fuel filter plays an important role in removing contaminants from fuel, and, hence, the effect of the difference in filter porosity needs to be observed with pressure difference across fuel filter monitored at the flow rate (0.03 m3/h and fuel temperature (15 ºC and 25 ºC). Furthermore, the effect of changes in temperature and surface morphology on the characteristics of filter was observed in this study. Based on FBT analysis, a polynomial regression (R^2 > 0.98) was used to describe the relationship between FBT value and the effect of biodiesel blends on filterability. It was concluded that the temperature, monoglyceride content, and FAME concentration in the diesel fuel influenced their FBT. However, the rise in waxy particles at 15°C (near Cloud Point) could result in a more significant average pressure drop than at 25˚C (ambient temperature). It was also found that a higher biodiesel mixture potentially results in a higher-pressure difference due to the lower fuel temperature and the formation of waxy contaminants that can clog the filter.

Keywords: Filterability Study, B40 Biodiesel Blends, Filter Blocking Tendency, Filter Rig Test, Pressure Drop

Received: 1st March 2023; Revised: 30th May 2023; Accepted: 20th June 2023; Available online: 2nd July 2023

1. Introduction

Biodiesel is an alternative fuel that boasts several advantages over traditional diesel fuel. One notable benefit is its high combustion efficiency, which contributes to improved overall engine performance. Additionally, biodiesel exhibits low concentrations of sulphur and aromatics, making it a favorable choice for use in diesel vehicles. In recent years, advancements in engine study have focused on reducing exhaust emissions while maintaining performance. Biodiesel, such as palm oil methyl esters, plays an important role as a leading alternative in diesel engine combustion (Kumar *et al.* 2019; Mejía *et al.* 2020). The utilization of biodiesel blends has gained traction in the automotive industry, offering a viable option that influences the lifespan of internal combustion engines in several beneficial ways. Biodiesel blends, especially those with a higher concentration, exhibit improved characteristics such as a higher cetane number, enhanced lubrication properties, and reduced emissions. In Indonesia, the automotive industry has been gradually increasing the percentage of biodiesel in blends, specifically up to 30% volume biodiesel (B30), since early 2020 (Kharina *et al.* 2016). The fundamental goal of recent advancements in engine technology has been to reduce emissions while maintaining engine performance. In this context, palm oil methyl ester has emerged as a primary commodity that effectively serves as a substitute for diesel fuel (Nguyen and Vu 2019; Tran *et al.* 2021; Doan *et al.* 2022). Previous studies have consistently demonstrated that palm biodiesel compares favorably to conventional fuel. Consequently, commercial fuel has approved the blending of low biodiesel and diesel ratios. However, the use of higher diesel blends poses a significant concern regarding the formation of deposits in the fuel filter due to the presence of monoglycerides (Tang, *et al.* 2008; Paryanto, *et al.* 2019) and accompanied by specifications of other quality standards (Van Gerpen 2015).

One of the issues encountered in filtration processes is filter clogging, which often leads to an increasing number of complaints over time (Fersner *et al.* 2014). This issue not only reduces the lifespan of the filter but also increases maintenance costs. Moreover, filter clogging can disrupt the functioning of fuel injection components in diesel engines, potentially causing damage (Cardeño *et al.* 2020). In addition to filter clogging, it is important to analyze the interaction between fuel and the filtration system, particularly in terms of dirt contaminants. Hard abrasive particles are the main culprits behind the initial wear and damage to precision injection pumps and injector surfaces

* Corresponding author:
Email: Yogi.dito17@gmail.com (Y. Pramudito)

https://doi.org/10.14710/ijred.2023.52801
ISSN: 2252-4940/© 2023.The Author(s). Published by CBIORE

(Stępień 2019). According to an experiment conducted by (Stępień 2019), particles with a size ranging from 1 to 5 micrometers are the most dangerous because they can gradually increase the clearance between the moving parts of the fittings, resulting in a decrease in the characteristics and operation of the injection pump and injector respectively. Therefore, it is crucial to optimize the use of fuel filter in order to have an optimum porosity to establish fuel flow in the filtration system.

Recent studies have highlighted certain limitations of biodiesel when used as a blend with diesel fuel, primarily due to its poor cold-flow characteristics (Joshi and Pegg 2007), which can lead to filter clogging. During the production process of biodiesel through esterification or transesterification reactions, impurities like saturated monoglycerides (SMG) can be generated, which tend to precipitate at low temperatures (Alleman *et al.* 2016). The formation of solid deposits above the Cloud Point (CP) is initiated by SMG (Chupka *et al.* 2012). Furthermore, it has been reported by Kim and Xiao *et al.* (2014) that biodiesel blends may experience fuel clogging when exposed to cold weather conditions. Depending on the total concentration of blends, the contaminants present can cause operational problems, even in fuel that comply with current quality standards (Cardeño, *et al.* 2020). The cold flow mechanism of biodiesel is showed in Figure 1. Saturated molecules are initiated near Cloud Point to form crystals that grow and form interlocking networks that must be closely monitored to ensure trouble-free operation in cold climates.

Currently, the issue of filter clogging is prevalent when using biodiesel, particularly at low temperatures. Various cold-flow characteristics of biodiesel, such as fog point, pour point, and precipitation, play a significant role in demonstrating its performance in colder conditions. It is also important to note that the precipitation of this fuel increases with lower operating temperatures, higher saturated monoglyceride content, and higher biodiesel concentrations in diesel oil (Ghaizani *et al.* 2018; Paryanto, *et al.* 2019). Therefore, the correct technique must be employed to properly anticipate any issues that may arise with the gasoline filter. Due to the high sensitivity of modern vehicle engines to fuel pollutants, the effect these contaminants have on fuel filter may directly affect the diesel engine's injection system (Komariah *et al.* 2018).

Recently, it was observed that vast differences in FBT values of biodiesel blends can potentially influence filtration behavior. Fuel with an FBT greater than 1.41 tends to clog fuel filter (Fersner *et al.* 2014) and (F. Cardeño, *et al.* 2020). Therefore, it was suggested that 1.41 should be used as a reasonable limit. In another study, it was recognized that an FBT with a value of 2 be referred to as “well-screened” and an FBT > 2 as “un-screened” according to standard DIN EN 590:2017e10 where a default value of 2.52 for FBT was set (Van Hoed *et al.* 2008). In Australia, however, an upper limit of 2.0 is applicable (Plata *et al.* 2015).

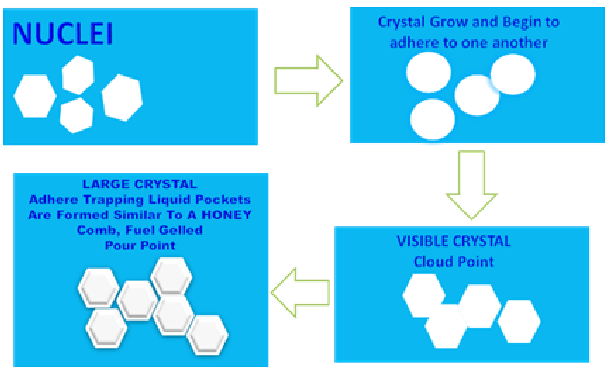

Fig. 1 Cold Flow Mechanism of Biodiesel (Verma, Sharma *et al.* 2016)

Several studies have been conducted to assess the filterability properties of diesel fuel with FBT (Filter Blocking Tendency) and filter pressure drop measurements. These studies aimed to determine the fuel filter lifespan in diesel engines using petroleum and biodiesel feedstocks such as soybean, rapeseed, and waste cooking oil (WCO). The results of these studies demonstrated an exponential increase in FBT with higher concentrations of biodiesel mixtures, specifically Karanja and WCO (Thangamani *et al.* 2021). In addition, another study investigated the filtration performance of crude Karanja oil and a commercial diesel filter across three processing stages, namely esterification and transesterification. The results indicated that the degumming mixture exhibited a significantly lower mean pressure difference compared to other tested mixtures (Vora *et al.* 2020). As previously stated, fuel filter blocking occurs due to tendency of the presence of saturated components in biodiesel and its blends to crystallize at low temperatures. It was found that the presence of biodiesel had no effect on the clogging characteristics compared to conventional diesel, and the presence of aromatics and derivatives of nitrogen has a much more detrimental effect on oxidative stability. This is in accordance with a recent study, which focused on identifying the factors responsible for filter clogging by using a filter rig on a High-Pressure Common Rail (HPCR) system (Gopalan *et al.* 2019). Furthermore, filter blockage can occur due to the accumulation of other impurities within the diesel engine filtration system. In one study, higher biodiesel blends, namely B30 and B40, were evaluated for their filterability properties using ASTM D 2068 Filter Blocking Tendency (FBT) and JIS 1617 filter rig tests to assess the pressure drop of the fuel filter. The study also discussed the total contaminant and cleanliness of the fuel. Moreover, it focused on a comprehensive filtration study of biodiesel blends with petroleum diesel fuel and palm-based biodiesel by measuring the filter pressure drop during long-term diesel engine operation. The experimental data obtained from these studies are expected to provide a more accurate understanding of the filter clogging issue.

2. Material and Methods

2.1 Sample preparation

In this study, a palm oil-based biodiesel (FAME) provided by an Indonesian biofuel company was used to create fuel test samples, specifically B30 and B40. These test samples were produced by blending 30% and 40% pure biodiesel with 70% and 60% petroleum-based diesel, respectively. The diesel component had a cetane number of 48. To investigate the physical and chemical properties of the biodiesel blend test samples, various characterization techniques were employed. The Filter Blocking Tendency (FBT) was measured according to the guidelines outlined in ASTM D 2068. The samples were subjected to filtration through a filter with a pore size of 1.6 um, maintaining a constant flow rate of 20 mL/minute. The pressure difference before and after filtration was continuously monitored until the pressure reached 105 kPa or until 300 mL of fuel had passed through the filter.

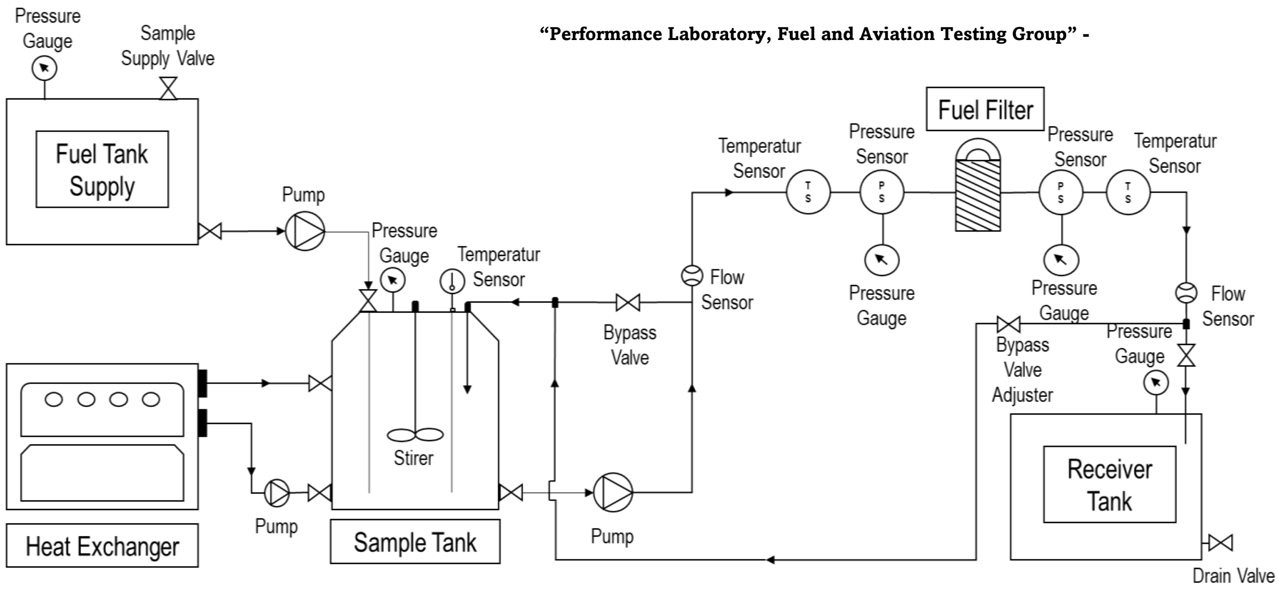

Fig. 2 Schematic of Filter Clogging Test Rig

2.2 Fuel Filter

In this study, four filter tests were conducted using two categories of fuel filter, namely, those designed for passenger vehicles and heavy-duty vehicles. Each test was carried out with a unique type of commercial fuel filter, which varied in terms of porosity and dimensions. The filters included a range of options, such as:

a. Type A filter (Filter A) with part number I2-13240 023-0 and a filter element made of paper filter media, specifically type AWJK 331 (55x12x67 2). The filter has an effective filtration area of 747.72 cm² and dimensions of 55 mm (width) x 12 mm (depth) x 67 mm (height). The filter element has a diameter of 80 mm and a height of 90 mm;
b. Type B filter (Filter B) with a honeycomb design, consisting of three layers (two spirals). The filter has an efficiency rating of five micrometers and a filter element diameter of 87 mm.
c. Type C filter, a heavy-duty vehicle fuel filter with a designation that also serve as water separators. It exhibits a thread size of M20 x 1.5 and a diameter of 93 millimeters. Furthermore, filter has a Length of 3.94 100 mm, a Gasket Outside Diameter of 65 mm, a Gasket Inside Diameter of 58 mm, and a 99% Efficiency at 30 microns. It also has an Efficiency Test Standard of SAE J806. Water that has been emulsified has a 95 percent efficiency rate. First Generation with Model: Spin-On.
d. Lastly, a type D filter (Filter D) has a high efficiency of 99%. It comprises three Micron Filter with a non-metallic cellulose media and has an outer diameter of 93 millimeters, a thread size of 1-14 UN, a length of 177 millimeters, a gasket with an outside diameter of 72 millimeters, and an inside diameter of 62 millimeters.

2.3 Cold Flow Characteristics of Fuel

To investigate the cold flow properties of the samples, various parameters were measured, including Cloud Point and Cold Filter Plugging Point (CFPP). The Cloud Point was measured using the ASTM D 5773 standard on a Cloud Point apparatus (Phase Tech. PCA-70Xi) equipped with a single-compartment cooling system capable of reaching temperatures as low as -55°C. On the other hand, the Cold Filter Plugging Point was measured in accordance with ASTM D 6371 using equipment from Linetronic Tech. To meet the specifications outlined in ASTM D7467 for Cloud Point, pour point, density, and kinematic viscosity of blends, multiple mixing ratios of palm biodiesel and diesel fuel were employed. These specifications were necessary to ensure that the palm biodiesel was suitable for use in diesel engines (Dey *et al.*, 2021).

2.4 Fuel Filter Pressure Drop

The measurement of pressure differences at different fuel flow rates was conducted according to the JIS standard D1617:1998 rates (Vora *et al.* 2020, Thangamani *et al.* 2021). A continuous fuel flow was established to monitor the pressure difference across the fuel filter, as illustrated in Figure 2. The test setup included a 50-liter fuel tank, a pump with a maximum flow capacity of 60 l/h, an electrical resistance heater and cooler with temperature specifications ranging from 10 to 50°C, pressure transducers capable of measuring up to 35 psi, thermocouples, flow meters, and the test filter. The biodiesel mixture was stored in the fuel tank, which was covered with a lid featuring inlet and outlet pipes to facilitate the continuous flow of the mixture throughout the evaluation. The static pressure across the filter was measured. The fuel intake temperature was monitored using thermocouples positioned at various points along the fuel lines. Additionally, a pressure transducer was employed to detect both the fuel input and output pressure. Subsequently, the filter element was removed from the housing and placed in a desiccator to prevent contact with airborne dust particles and avoid potential issues.

3. Results and Discussion

3.1 Fuel Properties of Base Fuel, B30 and B40

The distillation process of crude oil gradually produces diesel fuel, which consists of a wide range of hydrocarbons, each

Table 1
Test Results for B30, B35 and B40 Fuel Characteristics Compared with B0 and B100

Test Parameters	Test Results					Specification EN 16709	Test Method
	Pure Diesel Oil (B0)	B30	B35	B40	Biodiesel (B100)		
Cetane Number	48.2	52.5	53.4	54.3	57.6	min. 51	ASTM D 613
Density at 15 ºC (kg/m^3)	849.1	853.4	854.5	855.4	871.9	825-865	ASTM D 4056
Kinematic Viscosity at 40 ºC (cSt)	2.969	3.319	3.389	3.467	4.515	2.00-4.62	ASTM D 445
Sulfur Content (mg/kg)	2000	1400	1300	1200	10	-	ASTM D 5453
Cloud Point (ºC)	12.8	12.9	12.9	13.0	13.0	-	ASTM D 5773
Cold Filter Plugging Point (ºC)	10	12	12	12	12	-	ASTM D 6371
Pour Point (ºC)	9	11	11	11	11	-	ASTM D 5949
Water Content (mg/kg)	90	140	150	170	250	max. 500	ASTM D 6304
FAME Content (vol %)	0	29.8	35.1	39.9	-	24-30	ASTM D 7806
Total Contaminants (mg/L)	7.2	9.9	10.3	11.1	14.1	max. 24	ASTM D 6217
Cleanliness (ISO Code)	22/21/16	22/21/18	22/21/18	22/21/18	23/22/19	-	ASTM D 7619
Monoglyceride Content (mass %)	-	0.162	0.188	0.215	0.543	-	ASTM D 6584
Methyl Esters Content	-	-	-	-	98.69	-	EN 14103

with a different boiling point between approximately 180°C and 370°C. Diesel fuel typically ignites at around 350°C, with a lower limit of 220°C, indicating a faster ignition compared to gasoline, which typically ignites at 500°C (Reif 2014). In this study, a diesel oil with a minimum cetane number of 48 and a maximum sulfur content of 2000 ppm was utilized. This type of diesel is commercially available in Indonesia, alongside various other options. Table 1 provides the fuel characteristics of petroleum diesel, biodiesel, and their blends. It is evident that the addition of biodiesel results in a higher cetane number, density, and kinematic viscosity compared to pure diesel fuel. However, biodiesel does possess a higher water content and monoglycerides as a contaminant. The B30, B35, and B40 variations exhibit a Cloud Point of 13.0°C, indicating challenging conditions that increase the risk of filter clogging during a filter rig test at a temperature of 15°C.

Biodiesel, a plant-derived fuel, is produced through the conversion of fatty acids into methyl esters. This process involves the transesterification of triglycerides using methanol. In Indonesia, palm oil (*Elaeis guineensis*) is the primary source of biodiesel. Palm oil contains approximately 43-51% saturated fatty acids, 38-44% monounsaturated fatty acids, and less than 10% polyunsaturated fatty acids. The composition of palm oil-based biodiesel provides enhanced oxidation stability, characterized by an induction period of over 12 hours, an iodine number between 50 and 60 percent, a Cloud Point between 12 and 17°C, and a pour point between 9 and 13°C (Hoekman, Broch *et al.* 2012).

The obtained results from this study show that the methyl ester content in biodiesel sample ranged from 98.69 mass%, monoglyceride content of 0.543 mass%, water content of 250 ppm, Cold Filter Plugging Point value of 12 ºC, and a Cloud Point of 13 ºC. These values were determined in conjunction with Cold Filter Plugging Point value, as indicated in Table 1. It is important to note that biodiesel is particularly vulnerable to fuel f low and precipitation issues at low operating temperatures and under conditions where the dew point is lower than the temperature (Paryanto *et al.* 2019; Fathurrahman *et al.* 2022);

The diesel fuel samples used in the experiment had a Cloud Point between 12 and 13 ºC, and filter rig test was conducted at a temperature of 15 ºC, which is an extreme condition that increases the likelihood of filter blockage. Furthermore, the crystals of B30, B35, and B40 biodiesel variations were formed at a temperature of 12.9 ºC, which can clog filter at 12 ºC and reach the pour point at 11 ºC. These conditions simulate harsh circumstances that raise the risk of filter clogging.

3.2 Effect of Biodiesel Content on FBT

FBT is a fuel characteristic that evaluates the filterability properties of diesel fuel, biodiesel, and their mixtures, with kinematic viscosities ranging from 1.6 cSt to 6.0 cSt. The filterability of a sample is determined by its volume after filtration and the observed pressure rise after passing through a filter. Therefore, FBT analysis is used for quality control to evaluate the cleanliness of fuel, as changes in filtering

Table 2
Relationship Between Biodiesel Percentage and FBT

Filtration Parameters	Biodiesel Percentage (FAME) in Diesel Fuel (vol %)								
	0	5	10	15	20	25	30	35	40
FBT (25 ºC)	1.46	1.80	2.51	3.48	4.40	5.10	7.57	8.63	10.05
a. Volume	280	200	130	90	70	60	40	35	30
b. Pressure	105	105	105	105	105	105	105	105	105
FBT (15 ºC)	1.60	1.94	2.79	4.12	4.72	6.08	8.63	10.05	15.03
a. Volume	240	180	115	75	65	50	40	30	20
b. Pressure	150	150	150	150	150	150	150	150	150

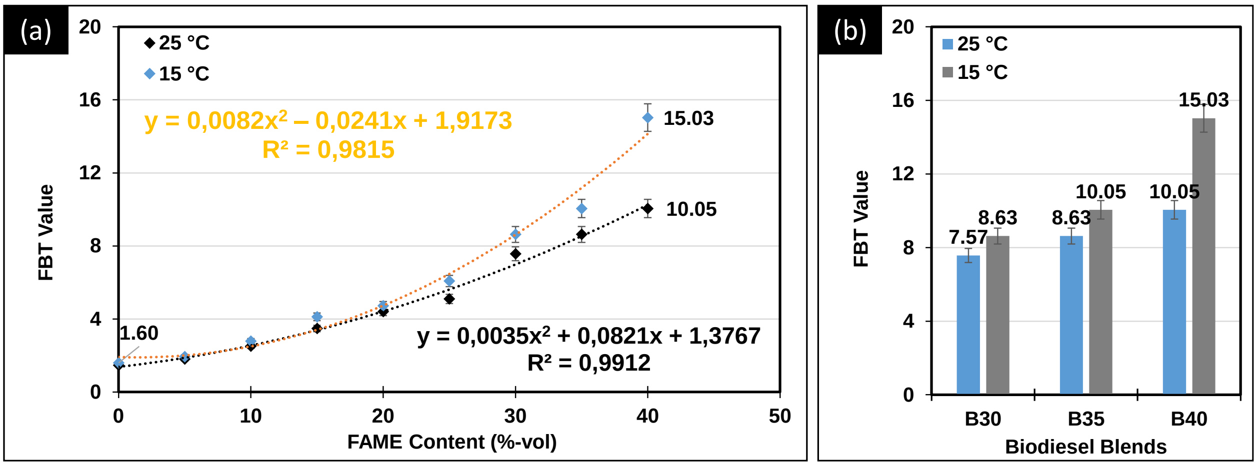

Fig 3. Effect of Biodiesel Percentage on FBT Value (a) and B30, B35, B40 (b)

performance after storage or pre-treatment can indicate a change in fuel conditions. Compared to product deterioration, FBT analysis is a viable option for assessing fuel quality. FBT ratings range from one to one hundred, with lower numbers indicating strong filterability and higher numbers indicating poor filterability. A lower FBT number means the fuel filter is less likely to become clogged, while a higher FBT value indicates lower filterability of the fuel fuel (Paryanto, Imam *et al.* 2022).

The effect of biodiesel content on the filtration characteristics of diesel engines is shown in Table 2. FBT value is an important indicator of filterability properties of diesel fuel, biodiesel, and their mixtures. Analysis was carried out at two different temperatures including 25 °C and 15 °C. Accordingly, FBT was evaluated at 15 °C to simulate extreme temperatures near fuel Cloud Point and at 25 °C to approximate typical room temperature. Figure 3 (a) shows FBT values of biodiesel blends test sample, with an inset figure for FBT of B30, B35, and B40. The effect of biodiesel blends on filterability is polynomial concerning FBT value, indicating that the temperature, monoglyceride content, and FAME concentration in diesel fuel all affected FBT value. For B30, B35 and B40 fuels, the measured FBT value at 25 °C is 7.57-10.05, while at 15 °C it is 8.63-15.03 as shown in Figure 3(b). Generally, when fuel is closer to its Cloud Point, the precipitation of monoglyceride molecules produces waxier (soft, like wax) impurities, and at lower temperatures, FBT rate may increase.

3.3 Filtration Analysis of B30 and B40

Further investigation was conducted to analyze the filtration of B30 and B40 test samples using a filter rig, to understand their filterability and pressure drop profile. It was observed that the links between filtered sample volume and the observed rise in pressure occurred after the sample passes through filter. Accordingly, porosity, structure, design, fluid flow, and test temperature all play a role in fuel filterability. In this test, the filtration performance was monitored and evaluated by assessing pressure drop throughout test under a specific temperature setting.

Figure 4 compares pressure difference using Filter A at 15°C and 25°C for B30 and B40 at a flow rate of 0.03 m3/h for 5 hours of running time. The obtained results showed that at 25°C, the two test samples did not exhibit any changes in pressure drop, indicating that filter blocking did not occur. However, at the lower temperature of 15°C, a pressure drop change took place indicating a filter blockage. B30 test sample showed a pressure drop increase of 40 kPa at 0.8 hours of filtration time, as determined by the intersection of the tangent lines. On the other hand, B40 test sample experienced a pressure drop increase of 80 kPa under identical circumstances but showed a pressure drop increase of 180 kPa at the tangent line intersections at 1.7 hours of filtering time. Under the exact circumstances, there was a 50 kPa pressure drop increase for B30, clearly indicating that the stability of the liquid phase of fuel changes at a low temperature near fuel Cloud Point. At this point, the monoglyceride molecules precipitate resulting in waxier

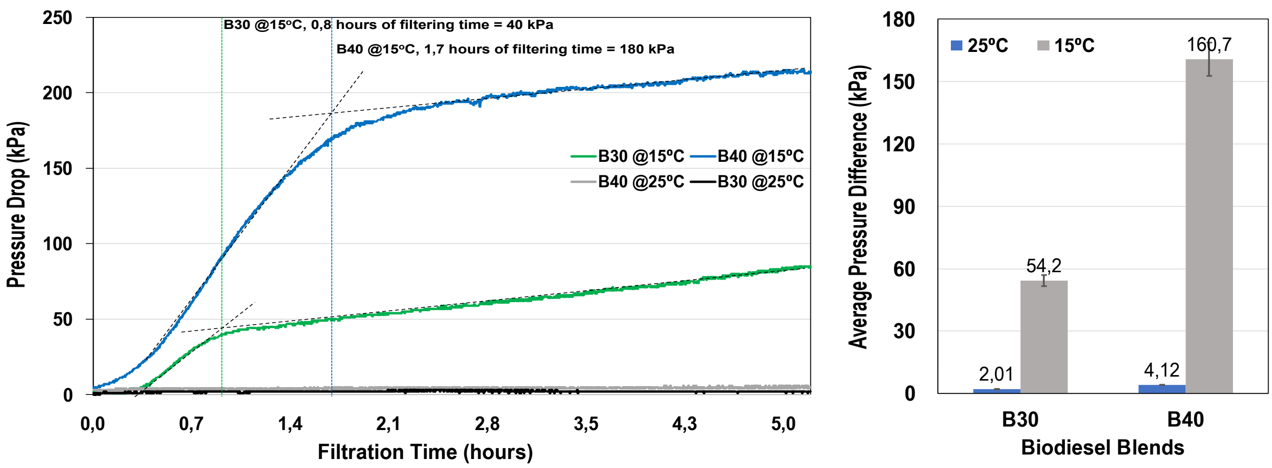

Fig. 4. Pressure Difference Comparison for Fuel Test Sample on Filter Rig Test at 15°C and 25°C Using Filter A

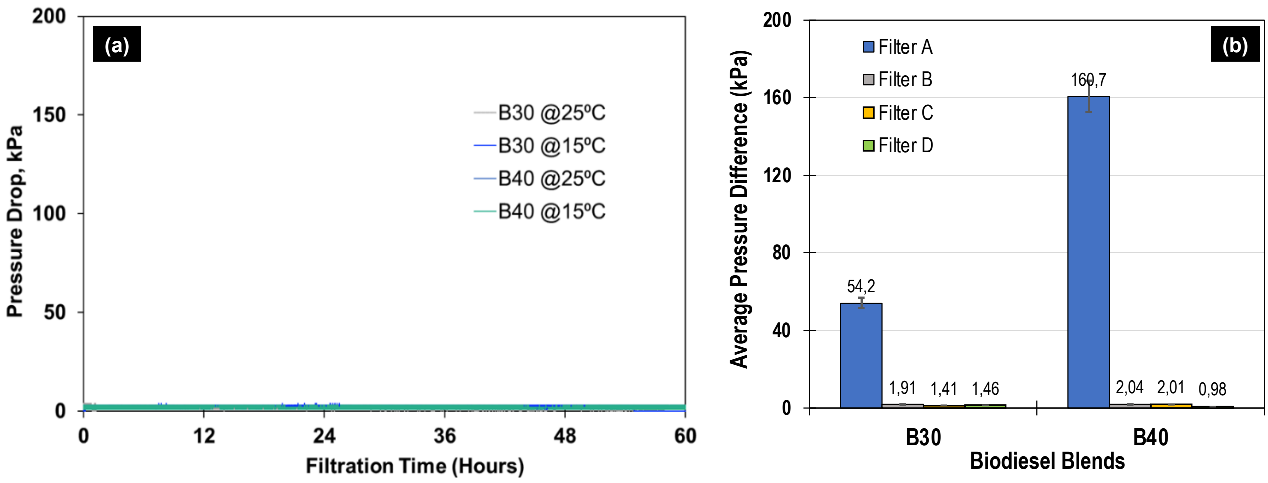

Fig. 5. Pressure Drop Profile for Filter B, Filter C, and Filter D on Filter Rig Test at 15ºC and 25ºC using B30 and B40 as Fuel Test Samples (No Pressure Drop Occurred) (a); and its Average Pressure Drop at 15ºC Compared to Filter A (b)

impurities that affect filterability. This led to the formation of precipitates initiated by monoglycerides (Fathurrahman *et al.* 2021; Fathurrahman *et al.* 2022). Furthermore, pressure difference increases when using B40 due to the higher amount of waxy contaminants and monoglycerides content compared to other fuel. It is important to note that the higher monoglyceride levels bring a measurable pressure drop in B40 (0.215 mass%) compared to B30 (0.162 mass%).

Figure 5 presents the results of the observation of pressure drop for the two samples fuel on filter rig using Filter B with 5-micron porosity at 15°C and 25°C for 60 hours. From the obtained results, it was found that Filter B, which comprises a different filter material and a lower porosity level, performed well during the 60-hour test, ensuring continuous flow and filtration of B30 and B40 fuel. Subsequently, test results on Filter A and B revealed that at 15°C, there was a change in pressure drop on filter near Cloud Point due to the presence of waxy contaminants. This interference was greater in Filter A than in Filter B. The results also showed that a lower filter porosity value affected pressure changes. Filter B, with honeycomb material and 5-micron porosity, did not exhibit filter blocking as compared to Filter A, which has a higher porosity level of 50-60 microns and AWJK paper as the primary material. Filterability of B30 and B40 test samples on Filter C with 30-micron porosity for 60 hours at 15°C and 25°C showed a lower pressure change in filter, which was similar to pressure change in Filter B. At 25°C, both samples had an average pressure drop ranging from 2.03 to 2.02 kPa, while at 15°C, they had a constant average pressure drop ranging from 1.41 to 2.01 kPa. Furthermore, no filter blocking was detected for Filter C on B30 and B40 test samples. Filter D also exhibited the same performance with an average pressure drop between 1.46 and 0.98 kPa for both test samples at 15°C.

Pressure rise observed during filter rig test was most likely caused by blocked fuel line valves or deposits, which limited the cross-sectional area, resulting in a specific flow rate. While these are considered as the primary causes, other possible causes such as contaminants or fuel deposits were intentionally created by the influence of temperature, as observed in this experiment. Accordingly, it is important to note that the possibility of deposit formation increases as the temperature of fuel approaches Cloud Point, and this further reduces the amount of space through which fuel can flow (Thangamani *et al.* 2021). These deposit layers can agglomerate into more extensive deposits, hence, reducing the amount of fuel that can flow through filter and resulting in a significant increase in pressure. If fuel has the potential to clog filter, it could cause a considerable drop in pressure. However, none of fuel samples tested showed any signs of filter clogging. Figure 5 shows that Filter B, C, and D exhibited normal filter performance for up to 60 hours.

3.4 Wax Morphology Analysis

To gain a better understanding of waxy filtration on a fuel filter, microscopic observation of wax precipitates was conducted. For this study, Filter A with a porosity size of 50 microns was used to evaluate the morphology of the waxy precipitate using a microscope. Figure 6 shows the visualization of the precipitate deposits at temperatures of 25°C and 15°C. The aim of these observations was to examine the impact of a

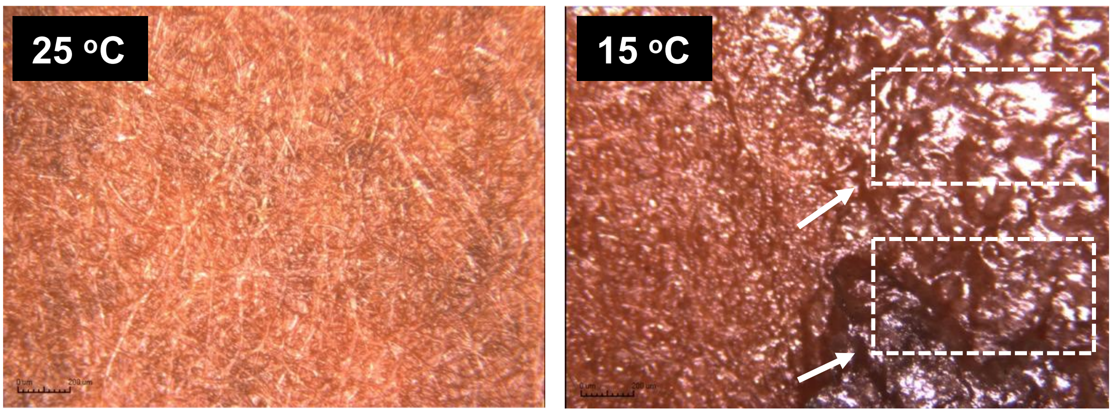

Fig 6. Microscopic Image of Waxy Precipitate Deposit Obtained from Filter Elements at Different Temperature

temperature drop on the crystallization of wax or the production of precipitate on Filter A. Furthermore, the discrepancies found in the visualization of the precipitate at 200x magnification (50 um scale) were shown to be influenced by fuel temperature.

The precipitate has a disc-like shape with a very high surface area, which allows it to build a network structure, resulting in a colloid that physically forms a gel. This gel forms when the nucleation site serves as a location for wax molecules to deposit. After a certain amount of time has passed and a certain temperature has been reached, the precipitated wax crystals take on a more regular shape and structure, which complicates the process of aggregation between the wax crystal networks (Norrman *et al*., 2016; Su *et al*., 2020; Yang *et al*., 2015).

Finally, this study examines the impact of using biodiesel blends containing up to 40% fuel, along with diesel engine fuel filters having varying porosities. Despite exploring the use in the transportation sector, no substantial variations were observed in the effects of the fuel filtration flow system on temperature and fuel flow. As a result, comprehensive studies are necessary in the future to examine the effects of different filtration flow systems and advancements in other renewable fuels, such as hydrotreated vegetable oil.

4. Conclusion

The study investigated the impact of B30 and B40 biodiesel blends on the filtration systems of diesel engines using both comparative analysis of FBT (ASTM D 2068) and filter rig (JIS 1617). The obtained results showed that the relationship between FBT value and the impact of biodiesel blends on filterability can be seen as a polynomial regression ($R^2 > 0{,}98$). It was evident that the temperature, FAME concentration, and monoglyceride content as a precursor of waxy precipitates in diesel oil influence their FBT. During the filtration test, at 25 °C, B30 and B40 indicated no substance blocking on Filter A, B, C, and D, with variations of porosity and filter paper media. However, at a lower temperature of 15°C, pressure drop changed, and a filter blockage only on Filter A was indicated with a higher porosity level of 50-60 microns and AWJK paper as the primary material. This phenomenon took place due to monoglyceride molecules precipitating near Cloud Point, resulting in waxier impurities affecting filterability of incompatible filter paper. Furthermore, it was evident from the findings that the higher biodiesel mixture, the higher pressure rises due to the lower fuel temperature and the formation of waxy contaminants that can clog filter. At the lower temperature of 15 °C, the change in pressure drop indicates a filter blockage. It was also found that monoglyceride molecules precipitated close to the Cloud Point, resulting in waxier impurities, and this affected the filterability. The obtained results show that the higher biodiesel mixture, and the higher pressure increases due to the lower fuel temperature and the formation of waxy contaminants that can clog filter.

Acknowledgment

The authors gratefully acknowledge the financial support from the Directorate of Research and Development, University of Indonesia, under the Hibah Publikasi Terindeks Internasional (PUTI) Pascasarjana NKB-306/UN2.RST/HKP.05.00/2022. Additionally, the authors would like to express their gratitude to the Fuel Characteristics and Performance Laboratory at the LEMIGAS committee for their assistance with the measurements

References

Alleman, T. L., McCormick, R. L., Christensen, E. D., Fioroni, G., Moriarty, K., & Yanowitz, J. (2016). *Biodiesel handling and use guide* (No. NREL/BK-5400-66521; DOE/GO-102016-4875). National Renewable Energy Lab.(NREL), Golden, CO (United States). https://www.osti.gov/biblio/1347103

Cardeño, F., Lapuerta, M., Rios, L., & Agudelo, J. R. (2020). Reconsideration of regulated contamination limits to improve filterability of biodiesel and blends with diesel fuels. *Renewable Energy,* 159, 1243-1251. https://doi.org/10.1016/j.renene.2020.06.079

Chupka, G. M., Fouts, L., & McCormick, R. L. (2012). Effect of low-level impurities on low-temperature performance properties of biodiesel. *Energy & Environmental Science*, 5(9), 8734-8742. https://doi.org/10.1039/C2EE22565D

Dey, S., Reang, N. M., Das, P. K., & Deb, M. (2021). A comprehensive study on prospects of economy, environment, and efficiency of palm oil biodiesel as a renewable fuel. *Journal of cleaner production*, 286, 124981. https://doi.org/10.1016/j.jclepro.2020.124981

Doan, Q. B., Nguyen, X. P., Dong, T. M. H., Pham, M. T., & Le, T. S. (2022). Performance and emission characteristics of diesel engine using ether additives: A review. *International Journal of Renewable Energy Development*, 11(1), 255-274. https://doi.org/10.14710/ijred.2022.42522

Fathurrahman, N. A., Nasikin, M., Yulizar, Y., & Khalil, M. (2022). Thermodynamic study on the prevention of B30 biodiesel wax crystallization by γ-Al2O3 nanoparticles and sorbitan monooleate. *Fuel*, 314, 123144. https://doi.org/10.1016/j.fuel.2022.123144

Fathurrahman, N. A., Wibowo, C. S., Nasikin, M., & Khalil, M. (2021). Optimization of sorbitan monooleate and γ-Al2O3 nanoparticles as cold-flow improver in B30 biodiesel blend using response surface methodology (RSM). *Journal of Industrial and Engineering Chemistry*, 99, 271-281. https://doi.org/10.1016/j.jiec.2021.04.037

Fersner, A. S., & Galante-Fox, J. M. (2014). Biodiesel feedstock and contaminant contributions to diesel fuel filter blocking. *SAE International Journal of Fuels and Lubricants*, 7(3), 783-791. https://www.jstor.org/stable/26273718

Ghaizani, M. A., Abdurrosyid, I., Paryanto, I., & Gozan, M. (2018). Monostearin effects on the formation of precipitate in palm oil biodiesel and petroleum diesel blends with various storage temperature. In *E3S Web of Conferences* (Vol. 52, p. 00026). EDP Sciences. https://doi.org/10.1051/e3sconf/20185200026

Gopalan, K., Chuck, C. J., Roy-Smith, C., & Bannister, C. D. (2019). Assessing the impact of FAME and diesel fuel composition on stability and vehicle filter blocking. *SAE International Journal of Advances and Current Practices in Mobility*, 1(2019-01-0049), 284-290." https://doi.org/10.4271/2019-01-0049

Hoekman, S. K., Broch, A., Robbins, C., Ceniceros, E., & Natarajan, M. (2012). Review of biodiesel composition, properties, and specifications. *Renewable and sustainable energy reviews*, 16(1), 143-169. https://doi.org/10.1016/j.rser.2011.07.143

Joshi, R. M., & Pegg, M. J. (2007). Flow properties of biodiesel fuel blends at low temperatures. *Fuel*, 86(1-2), 143-151. https://doi.org/10.1016/j.fuel.2006.06.005

Kharina, A., Malins, C., & Searle, S. (2016). Biofuels policy in Indonesia: Overview and status report. Washington DC, USA: *International Council on Clean Transportation*. https://theicct.org/wp-content/uploads/2021/06/Indonesia-Biofuels-Policy_ICCT_08082016.pdf

Kim, K., Xiao, K., Kittelson, D. B., & Pui, D. Y. (2014). Pressure drop hysteresis effect on biodiesel filtration. *Fuel*, 115, 629-635. https://doi.org/10.1016/j.fuel.2013.07.079

Komariah, L. N., Hadiah, F., Aprianjaya, F., & Nevriadi, F. (2018, September). Biodiesel effects on fuel filter; assessment of clogging characteristics. In *Journal of Physics: Conference Series* (Vol. 1095, No. 1, p. 012017). IOP Publishing. https://doi.org/10.1088/1742-6596/1095/1/012017

Kumar, A. N., Kishore, P. S., Raju, K. B., Kasianantham, N., & Bragadeshwaran, A. (2019). Engine parameter optimization of palm oil biodiesel as alternate fuel in CI engine. *Environmental*

Science and Pollution Research, 26, 6652-6676. https://doi.org/10.1007/s11356-018-04084-z

Mejía, A., Leiva, M., Rincón-Montenegro, A., Gonzalez-Quiroga, A., & Duarte-Forero, J. (2020). Experimental assessment of emissions maps of a single-cylinder compression ignition engine powered by diesel and palm oil biodiesel-diesel fuel blends. *Case Studies in Thermal Engineering*, 19, 100613. https://doi.org/10.1016/j.csite.2020.100613

Nguyen, X. P., & Vu, H. N. (2019). Corrosion of the metal parts of diesel engines in biodiesel-based fuels. I*nternational Journal of Renewable Energy Development*, 8(2), 119. https://doi.org/10.14710/ijred.8.2.119-132

Norrman, J., Solberg, A., Sjoblom, J., & Paso, K. (2016). Nanoparticles for waxy crudes: effect of polymer coverage and the effect on wax crystallization. *Energy & Fuels*, 30(6), 5108-5114. https://doi.org/10.1021/acs.energyfuels.6b00286

Paryanto, I., Budianta, I. A., Alifia, K. C. H., Hidayatullah, I. M., Darmawan, M. A., Judistira, & Gozan, M. (2022). Modelling of Fuel Filter Clogging of B20 Fuel Based on the Precipitate Measurement and Filter Blocking Test. *ChemEngineering*, 6(6), 84. https://doi.org/10.3390/chemengineering6060084

Paryanto, I., Prakoso, T., Suyono, E. A., & Gozan, M. (2019). Determination of the upper limit of monoglyceride content in biodiesel for B30 implementation based on the measurement of the precipitate in a Biodiesel–Petrodiesel fuel blend (BXX). *Fuel*, 258, 116104. https://doi.org/10.1016/j.fuel.2019.116104

Plata, V., Gauthier-Maradei, P., Romero-Bohórquez, A. R., Kafarov, V., & Castillo, E. (2015). Characterization of insoluble material isolated from Colombian palm oil biodiesel. *Biomass and Bioenergy*, 74, 6-14. https://doi.org/10.1016/j.biombioe.2014.12.024

Reif, K. (2014). Diesel engine management. Berlin: *Springer Vieweg*. https://doi.org/10.1007/978-3-658-03981-3

Stępień, Z. (2019). The influence of particulate contamination in diesel fuel on the damage to fuel injection systems. *Combustion Engines*, 58. http://dx.doi.org/10.19206/CE-2019-213

Su, B., Wang, L., Xue, Y., Yan, J., Dong, Z., Lin, H., & Han, S. (2021). Effect of Pour Point Depressants Combined with Dispersants on the Cold Flow Properties of Biodiesel-Diesel Blends. *Journal of the American Oil Chemists' Society*, 98(2), 163-172. https://doi.org/10.1002/aocs.12456

Tang, H., Salley, S. O., & Ng, K. S. (2008). Fuel properties and precipitate formation at low temperature in soy-, cottonseed-, and poultry fat-based biodiesel blends. *Fuel*, 87(13-14), 3006-3017. https://doi.org/10.1016/j.fuel.2008.04.030

Thangamani, S., Sundaresan, S. N., Barawkar, V. T., & Jeyaseelan, T. (2021). Impact of biodiesel and diesel blends on the fuel filter: A combined experimental and simulation study. *Energy*, 227, 120526. https://doi.org/10.1016/j.energy.2021.120526

Tran, V. D., Le, A. T., & Hoang, A. T. (2021). An experimental study on the performance characteristics of a diesel engine fueled with ULSD-biodiesel blends. *International Journal of Renewable Energy Development*, 10(2), 183. https://doi.org/10.14710/ijred.2021.34022

Van Gerpen, J. (2015). Cold soak filtration test. B*iodiesel TechNotes are published by the National Biodiesel Education Program at the University of Idaho, Issue TN*, 19. https://www.biodieseleducation.org/Literature/TechNotes/TN19_ColdSoakFiltrationTest.pdf

Van Hoed, V., Zyaykina, N., De Greyt, W., Maes, J., Verhé, R., & Demeestere, K. (2008). Identification and occurrence of steryl glucosides in palm and soy biodiesel. *Journal of the American Oil Chemists' Society*, 85(8), 701. https://doi.org/10.1007/s11746-008-1263-5

Verma, P., Sharma, M. P., & Dwivedi, G. (2016). Evaluation and enhancement of cold flow properties of palm oil and its biodiesel. *Energy Reports*, 2, 8-13. https://doi.org/10.1016/j.egyr.2015.12.001

Vora, R., Kadam, V., & Thangaraja, J. (2020). Experimental investigation on the filtration characteristics of a commercial diesel filter operated with raw and processed karanja-diesel blends. *Sādhanā*, 45, 1-8. https://doi.org/10.1007/s12046-020-01394-2

Yang, F., Paso, K., Norrman, J., Li, C., Oschmann, H., & Sjoblom, J. (2015). Hydrophilic nanoparticles facilitate wax inhibition. *Energy & Fuels*, *29*(3), 1368-1374. https://doi.org/10.1021/ef502392g