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# SEDIMENT FORMATION IN A PALM OIL BIODIESEL BLEND IN A SHIP FUEL TANK

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## ABSTRACT

*In this study, sediment formation in a ship fuel tank fuelled with a blend of 30% palm biodiesel (B30) was evaluated. The main objective was to understand sediment formation during fuel storage over different storage periods, which has not been previously reported. In this study, B30 was evaluated for cleanliness, water content, contaminants and other properties before it was stored in a ship fuel tank for 30 days. Regular sampling was conducted every two days during this storage period to monitor and analyse sediment formation. After a storage period of 30 days, B30 exhibited density comparable to its initial condition, with a difference of less than 0.1%. However, its viscosity showed an increase of 1.2%. In contrast, no significant difference was observed in fuel cleanliness based on ISO 4406 and in the measured water content. The amount of sediment formed was consistent up to the 19th day, but from the 20th to the 30th day, it rapidly increased logarithmically, with a 312% mass increase by the 30th day. Additionally, morphological and FTIR analyses showed that the sediment consisted of agglomerated asphaltene and saturated fatty acids. This study reveals that quality control and specific treatments are required in B30 to suppress the formation of sediments.*

**Keywords:** cleanliness, palm oil biodiesel, sediment formation, storage stability.

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## INTRODUCTION

Biodiesel is a new form of renewable energy (He & Van Gerpen, 2012) that consists of fatty acid methyl esters (FAME) or ethyl esters, which are sourced from animal or vegetable fats through a transesterification process (Mehmood *et al*., 2016; Sebayang *et al*., 2023). These fuels are environmentally friendly and promising alternatives that can meet the world's energy needs as a substitute for fossil fuels (Sun & Li, 2019). The fuel is classified as low-emission, nontoxic and easily decomposable (Garcia *et al*., 2020; Okoye *et al*., 2019; Sun & Li, 2019).

In Indonesia, various studies have been conducted to improve biodiesel FAME properties and reduce dependence on fossil fuels. Indonesia has been using a mixture of 30% biodiesel and 70% diesel fuel (B30), and the biodiesel proportion will soon increase to 40%. The Indonesian government has mandated biodiesel use in the industrial sector, land and sea transportation [Minister of Energy and Mineral Resources (MEMR), 2014]. Biodiesel implementation in Indonesia is strongly supported by the successful durability testing of biodiesel-blended fuel, particularly for land applications, including truck, train, bus and passenger car transport, which have no issues.

However, the use of biodiesel for marine vessels still presents numerous challenges, especially under environmental conditions with high water content and condensation on the walls of storage tanks. These factors require careful consideration, as they significantly affect biodiesel quality (Fregolente *et al*., 2012). In addition, the large capacity of ship tanks differs from that of land

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vehicles. On board the vessel, the fuel tank cannot be completely depleted, leading to the mixing of old fuel with new fuel during refuelling. Moreover, ships move dynamically to various regions, which pose a challenge for maintaining fuel quality when refuelling in different places.

Differences in raw material suppliers will affect changes in properties such as density, viscosity, cleanliness and water content (Fersner & Galante-Fox, 2014; Rao & Reddy, 2023). Viscosity, cleanliness, and density are also important properties of biodiesel (Ramos *et al*., 2008). Viscosity also dramatically affects ignition in the engine and will determine the fuel's combustion quality. High viscosity will cause large spray size and can cause poor combustion (Ceriani *et al*., 2007; Tesfa *et al*., 2010). Biodiesel blends can reduce viscosity by approximately 12.9% (Lin, 2013). Viscosity can also cause a decrease in the quality of injection and decreased pressure (Srichai *et al*., 2018). Density is critical because it affects the quality of the mixture in the combustion chamber, the energy produced, and the injection system (Li *et al*., 2019; Noor *et al*., 2018; Tesfa *et al*., 2010). Density will affect the atomisation of the fuel (Silitonga *et al*., 2016). High density will cause incomplete combustion (Erdmann *et al*., 2019).

The water content in biodiesel can originate from condensation at the tank's surface and the accumulation of fuel vapours (Hill & Hill, 2008). The presence of water allows the formation of microorganisms in biodiesel (Hettige & Sheridan, 1989; Zhang *et al*., 2011). Biodiesel also has hygroscopic properties, *i.e.*, it quickly absorbs water from the environment. Water absorption can lead to the formation of fatty acids, resulting in corrosion issues (Fregolente *et al*., 2012). Furthermore, the high water content will cause sedimentation at the bottom of the tank and can drive the growth of microorganisms (Passman, 2013). The presence of microorganisms can impact the deterioration of biodiesel fuel quality. These conditions are attributed to the composition of biodiesel, which contains an ester that is readily used by microorganisms, unlike hydrocarbons (Hettige & Sheridan, 1989). The presence of these microorganisms can result in the emergence of contaminants, resulting in sludge development (Chao *et al*., 2010).

Various types of contaminants have been found in biodiesel, such as glycerine, water, sulfur, sterile glucosides, microbial sediments and other sediments that need further research and exceptional attention to maintain the quality of biodiesel (Fersner & Galante-Fox, 2014; He & Van Gerpen, 2012). These contaminants have caused significant detrimental effects (Fersner & Galante-Fox, 2014), so various methods have been taken to avoid this situation. If this problem occurs continuously, it will cause fuel filters to become clogged, shorten their service life and even cause the engine to not operate optimally because it cannot supply sufficient fuel flow (Jaroonjitsathian *et al*., 2016; Thangamani *et al*., 2021). Wang *et al.* (2009) reported that steryl glucoside (SG) was the main contributor to the formation of deposits in soybean biodiesel. In addition, SG is a natural derivative of vegetable or animal oil. It can contribute to problems with the flow ability of biodiesel and biodiesel mixtures and lead to clogged filters (Lee *et al*., 2007). Moreover, deposits will cause the injector to clog (Kumar, 2017). Therefore, these deposits can form on the injectors, valves and piston crowns due to the mixing of biodiesel with diesel (Sugiarto *et al*., 2020a; 2020b). The deposit composition leads to dead ends and corrosion (Hidayat & Sugiarto, 2020; Sugiarto *et al*., 2021).

Various studies have examined the formation of sediments from multiple sources in established storage tanks. Tang *et al*. (2008) used a 20% soy, cottonseed and biodiesel base with 80% ultra-low sulfur diesel (ULSD) to observe precipitate formation. They conducted precipitate testing using glass bottles for storage. Bücker *et al*. (2010) utilised 0%, 5%, 10% and 20% biodiesel soy oil to determine the growth of microbial contaminants by simulating storage. Tang *et al*. (2008) conducted research to determine the growth of fungi in various mixtures of biodiesel from soybeans as a function of time in the laboratory. Mushrush *et al*. (2011) investigated the stability of sediment formed from 5% soybean biodiesel in a borosilicate brown glass bottle. Na-Ranong and Kitchaiya (2014) used pure biodiesel to determine the effect of contaminants such as monoglycerides, diglycerides and triglycerides on biodiesel storage. Gozan *et al.* (2022) conducted precipitation tests to predict contaminant formation using a 20% FAME and 80% diesel fuel (B20) medium based on monoglyceride content in tanks on land. Silva *et al*. (2021) predicted the effect of the addition of 20% and 10% soybean biodiesel to marine diesel on sludge formation over 28 days of storage with a simulated storage method.

Many of these research studies focused on the formation of contaminants under simulated conditions instead of actual conditions, such as those in existing ship tanks. Moreover, only a few studies have fully accounted for the factors that affect storage, including environmental conditions, variations in the quality of biodiesel fuel sources, and requirements for transportation equipment during conveyance from producers to consumers. Therefore, this study investigated sediment formation based on actual conditions on a ship, especially in tropical areas, such as Indonesia, which has not been reported previously. When a ship operates, it will depart from one site and travel to various other sites and refuel in particular areas and the different fuels will mix in the ship's tanks. Refuelling in specific areas cannot be avoided because the vessel cannot return to the initial refuelling point. Due to different refinery technologies, the different fuels might have varying properties.

Therefore, this study aimed to measure the growth of contaminants in the dynamic fuel tanks of vessels and to study the effect of storage time on changes in the properties of palm biodiesel. The amount of sediment formed from a palm methyl ester blend fuel with a volume ratio of 30% biodiesel and 70% diesel fuel (B30) in the fuel tank of a ship was measured at various storage times, which other researchers have not reported. Therefore, the result can be used to predict how quickly sediment can accumulate to form sludge in fuel tanks. Furthermore, fuel cleanliness, viscosity, density and water content were tested to study the properties of palm biodiesel in a dynamic storage tank in specific periods.

## MATERIALS AND METHODS

### Fuels

In this study, the fuel used was a B30 biodiesel mixture supplied by two filling points and sourced from a ship's tank. The ship's tank was cleaned first above the docking in the shipyard before it was loaded into the ship. Then, the ship's tank was filled with biodiesel fuel using a barge and a tanker truck. In this study, the B30 palm biodiesel blended fuels came from two places in Indonesia, Sample 1 (X) and Sample 2 (Y). The visual appearance of both samples is shown in *Figure 1*. Sample 1 is brighter with fewer small black particles than Sample 2. Visual inspection showed that both samples were free from water content.

*Figure 1. Visual appearance of (a) Sample 1(X) and (b) Sample 2 (Y).*

The fuel storage tank was first loaded with Sample 1 at a volume of 18,000 L, and two days later, it was refilled with 1,600 L of Sample 2. Then, fresh samples of Samples 1 and 2 were taken directly from a tanker truck to evaluate fuel characteristics. The storage tank capacity was 20,000 L, and it had dimensions of 4.50 × 3.40 × 1.25 m for the tank's length, width, and height. The vessel tank was made of steel.

### Sediment Test

Sediment formation was measured in B30 fuel based on the total contaminants in B30 palm biodiesel in the ship's tank. Fuel samples were taken from the source tank during filling and from the vessel directly after filling from the tank's bottom, middle, and top. Samples were taken at filling time and every two days thereafter for one month.

The aim of the B30 fuel contaminants test was to determine the amount of sediment collected at a particular total contaminant value, the formation of contaminants in the ship's tanks, and the feedstock's effect on contaminant formation. This test was performed to measure sediment formation caused by the accumulation of contaminants. The first test samples for Sample 1 and Sample 2 were treated by placing 100 mL of each B30 sample in a closed 100 mL separating funnel. Each sample was vacuum filtered through 0.8 micron filter paper.

For the second test, samples were taken from the bottom, middle, and top of the tank with volumes reaching 1 L every two days for 30 days. 100 mL of each sample of B30 was placed in a closed 100 mL separatory funnel. Each sample was vacuum-filtered through 0.8 micron filter paper. A Whatman™ cellulose acetate membrane filter was used to filter B30 fuel, and it had a 47 mm diameter and 0.8 micron particle retention. The sediment retained on the filter paper was washed with a petro-ether, dried under vacuum, and then weighed.

### Characteristics of Biodiesel Blends

The fuel properties tested, including viscosity at 40°C and density at 15°C measured using Anton PAAR SVM 3001 cold properties and using ASTM D445 and ASTM D1298 standards, respectively, reflect the cleanliness of the biodiesel fuel mixture. The device has good repeatability and reproducibility, approximately 0.10% and 0.35%, respectively. Cleanliness was measured using the Argo Hytos OP Count Particle Counter using standard ASTM D7596, and water content was measured using Karl Fischer Coulometric Titration using standard D1744. The first test samples consisted of Sample 1 and Sample 2, and the second test consisted of samples from the ship's tanks, which were taken at random from the bottom of the tank based on storage time. Specifically, sample 1+2 (1st day) was from 1 day of storage, 1+2 (15th day) was from 15 days of storage, and 1+2 (30th day) was from 30 days of storage.

The measurement uncertainty value was obtained from the uncertainty that arises from statistical data involving the calculation of several parameters, including the arithmetic mean, standard deviation, and degrees of freedom based on test reports and measuring instrument data sheets. All experimental steps are depicted in the flowchart shown in *Figure 2*.

## RESULTS AND DISCUSSION

### Viscosity and Density

Viscosity testing was conducted in this study to determine changes that occurred during fuel storage in the ship's fuel tank. Based on the results in *Table 1*, it can be seen that the results obtained for the viscosity of Sample 1 originating from source X showed a high value of approximately 3.45 mm$^2$/s, while that from source Y, namely, Sample 2, had a lower viscosity value of 3.23 mm$^2$/s. According to the MEMR, the values should be in the range of 2.00-4.50 mm$^2$/s, and according to ASTM D6751, it should be between 1.90-6.00 mm$^2$/s. Therefore, the sample met both standards. However, that value of Sample X was close to the maximum allowable limit. After mixing Sample 1 and 2 (X + Y), the viscosity changed to 3.30 mm/s$^2$ and continued to increase up to 30 days of storage and may have continued to increase with increasing storage time. If it continued to increase, it would affect the atomisation of biodiesel used as engine fuel (Ayoob & Fadhil, 2019), and if the viscosity is very high, it can cause large jet size and lead to poor combustion (Ceriani *et al*., 2007; Tesfa *et al*., 2010). Based on the maximum standard permitted by the MEMR, the value should be 2.0-4.5 mm$^2$/s (MEMR, 2019), and according to ASTM D6751, it should be between 1.90 and 6.00 mm$^2$. Therefore, the sample met both standards.

The results in *Table 1* for the density test show that the density value was relatively stable, as in previous studies where the density tended to be stable after approximately a month of storage (Hidayat *et al*., 2021). In *Table 1*, Sample 1 is the biodiesel from site X showing a high value of 836 kg/m$^3$ compared to Sample 2 from site Y, at 832 kg/m$^3$. After samples X and Y (1+2) were mixed, the density changed to 835 kg/m$^3$ and continued to increase up to 30 days of storage. Based on the maximum standard permitted by the MEMR, the density value should be 810-860 kg/m$^3$, and based on these results, it was below the permitted quality standard of the MEMR (MEMR, 2019). However, based on ASTM D 6751, biodiesel density must be 860-880 kg/m$^3$, and according to EN 14214, it should be in the 860-900 kg/m$^3$ range. Therefore, the density of biodiesel from X and Y sources did

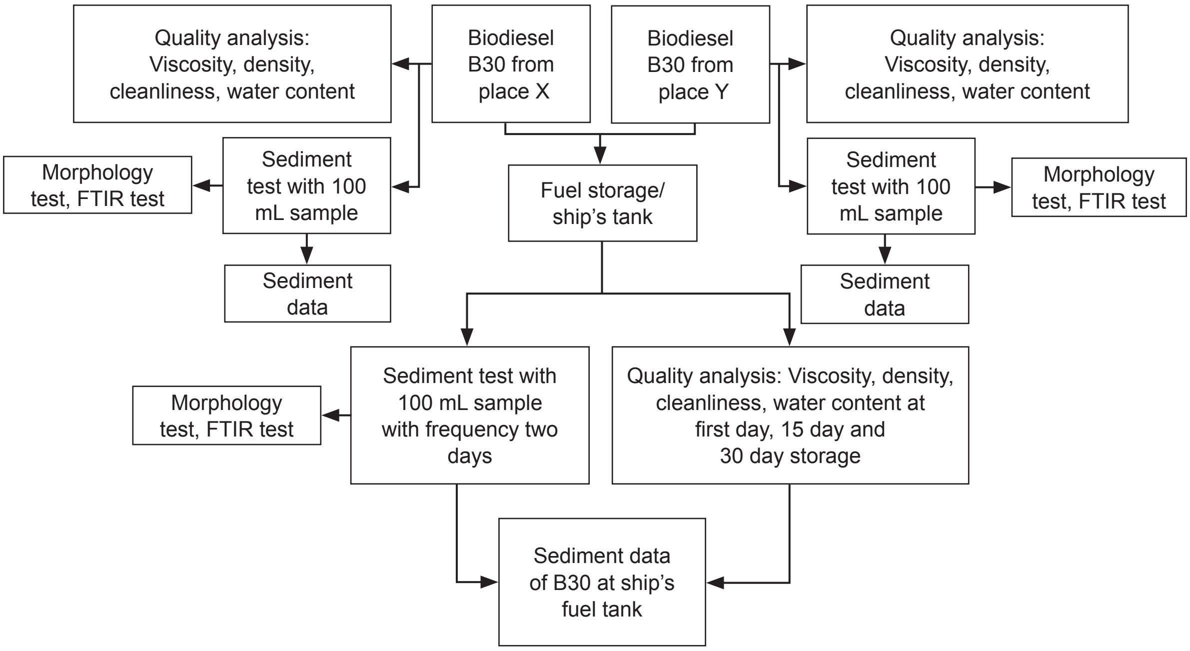

*Figure 2*. *Flowchart of the sediment test to measure sludge formation in the ship's fuel tanks.*

not meet these two standards, so it would affect the atomisation of biodiesel used as engine fuel (Silitonga *et al.*, 2016).

**TABLE 1. VISCOSITY AND DENSITY RESULTS**

| No. | Sample | Viscosity ($mm^2/s$) | Density ($kg/m^3$) |
|---|---|---|---|
| 1 | 1 | 3.45 | 836 |
| 2 | 2 | 3.23 | 832 |
| 3 | 1+2 (1st day) | 3.30 | 835 |
| 4 | 1+2 (15th day) | 3.32 | 835 |
| 5 | 1+2 (30th day) | 3.34 | 835 |

## Cleanliness and Water Content

The method used for cleanliness testing was the ASTM D7596 standard. Additionally, the most common standard code for the amounts of contaminants screened is ISO 4406. The purpose of this code is to simplify the reporting of particle count data by converting the number of particles into broad classes or regulations, in which a value increase of one generally indicates a doubling of the level of contamination, as shown in *Table 2*. The standard sizes used are 4, 6 and 14 µm. The results of the tests carried out are listed in *Table 3* and *4*.

*Table 3* shows the distribution of contaminants from the test results based on filter sizes of 4, 6 and 14 µm. *Table 4* shows the results for converting the number of contaminants to the ISO 4406 code. The table shows the level of cleanliness of the test samples based on storage time. The highest cleanliness results obtained for Sample 1, namely, at 4 microns (366,472), 6 microns (110,971), and 14 microns (5,871), with a cleanliness code of 26/24/20 compared to the others. In Sample 2, the cleanliness test results were at 4 microns (82,339), 6 microns (26,912), and 14 microns (286), with a cleanliness code of 24/22/15. This result shows that a difference in refuelling location leads to differences in cleanliness levels. Based on the test results, the two samples did not meet the standards set by the Worldwide Fuels Charter, namely, 18/16/13 for 4, 6 and 14 µm, respectively [International Organization for Standardization (ISO), 2017].

**TABLE 2. ALLOCATION OF SCALE NUMBER ISO 4406**

| Number of particle (mm) | | Scale number |
|---|---|---|
| **More than** | **Up to and including** | |
| 2,500,000 | | >28 |
| 1,300,000 | 2,500,000 | 28 |
| 640,000 | 1,300,000 | 27 |
| 320,000 | 640,000 | 26 |
| 160,000 | 320,000 | 25 |
| 80,000 | 160,000 | 24 |
| 40,000 | 80,000 | 23 |
| 20,000 | 40,000 | 22 |
| 10,000 | 20,000 | 21 |
| 5,000 | 10,000 | 20 |
| 2,500 | 5,000 | 19 |
| 1,300 | 2,500 | 18 |
| 640 | 1,300 | 17 |
| 320 | 640 | 16 |
| 160 | 320 | 15 |
| 80 | 160 | 14 |
| 40 | 80 | 13 |
| 21 | 40 | 12 |
| 10 | 20 | 11 |

Source: (ISO, 2017).

After mixing, there was a change in the level of cleanliness. For the 1+2 sample (1st day), the distribution of contaminants at sizes of 4 microns (26,404), 6 microns (8,100), and 14 microns (551) had the cleanliness code 22/20/16; for the 1+2 sample (15th day), contaminant distribution at sizes of 4 microns (21,624), 6 microns (6,107), and 14 microns (373) had a cleanliness code 22/20/16; and in sample 1+2 (30th day), the distribution of contaminants at sizes of 4 microns (27,511), 6 microns (8,149), and 14 microns (587) had the cleanliness code 22/20/16. The test results showed a decrease in the distribution of contaminants or an increase in the cleanliness code level compared to the blending of Sample 1 and Sample 2. However, these results did not meet the standards set by the Worldwide Fuels Charter. The maximum cleanliness limits of diesel fuel specified by the Worldwide Fuels Charter are 18/16/13 for 4, 6 and 14 µm, respectively (ISO, 2017). If this condition is not resolved, it will lead to injector blockage and affect engine performance.

**TABLE 3. CLEANLINESS TEST RESULTS**

| Sample | >4 µm | >6 µm | >14 µm |
|---|---|---|---|
| 1 | 366,472 | 110,971 | 5,871 |
| 2 | 82,339 | 26,912 | 286 |
| 1+2 (1st day) | 26,404 | 8,100 | 551 |
| 1+2 (15th day) | 21,624 | 6,107 | 373 |
| 1+2 (30th day) | 27,511 | 8,149 | 587 |

The test results show that the blending of different biodiesels affects the level of cleanliness of the biodiesel blend. In addition, the dynamic movement of ships affects the distribution of contaminants and the level of cleanliness of the blended biodiesel fuel with varying test results.

TABLE 4. CLEANLINESS TEST RESULTS BASED ON ISO 4406 CODE

| Sample | >4 µm | >6 µm | >14 µm |
|---|---|---|---|
| 1 | 26 | 24 | 20 |
| 2 | 24 | 22 | 15 |
| 1+2 (1st day) | 22 | 20 | 16 |
| 1+2 (15th day) | 22 | 20 | 16 |
| 1+2 (30th day) | 22 | 20 | 16 |

Source: (ISO, 2017).

Water is the primary source of contaminants in fuel. Testing for water content was carried out based on ASTM D1744, with the results listed in *Table 5* which shows that Sample 2 had higher water content, at 395 ppm, compared to Sample 1, at 372 ppm. These results indicate that the different refuelling locations also differ with respect to the water content of the fuel. The two samples did not meet the maximum average set by the government, namely, 300 ppm (MEMR, 2019).

After fuel mixing, the water content decreased by 313 ppm and was relatively stable over 30 days of storage in the ship's tank. However, the sample did not meet the maximum average set by the government, 300 ppm (MEMR, 2019). If this continued, the fuel properties would impact the occurrence of corrosion and the growth of microorganisms, which would cause the formation of sludge at the bottom of the tank, which would lead to filter blockage, clogged injectors and a clogged fuel system.

TABLE 5. WATER CONTENT RESULTS

| Sample | Water content (ppm) |
|---|---|
| 1 | 372 |
| 2 | 395 |
| 1+2 (1st day) | 313 |
| 1+2 (15th day) | 312 |
| 1+2 (30th day) | 313 |

## Sediment Formation Test Results

The sediment content values for the biodiesel B30 from locations X and Y were 0.031 ± 0.006 g/L and 0.017 ± 0.011 g/L, respectively. These results show that the sediment content in fuel from city X was higher than that in city Y. These results indicate differences in the quality of biodiesel fuel from these samples.

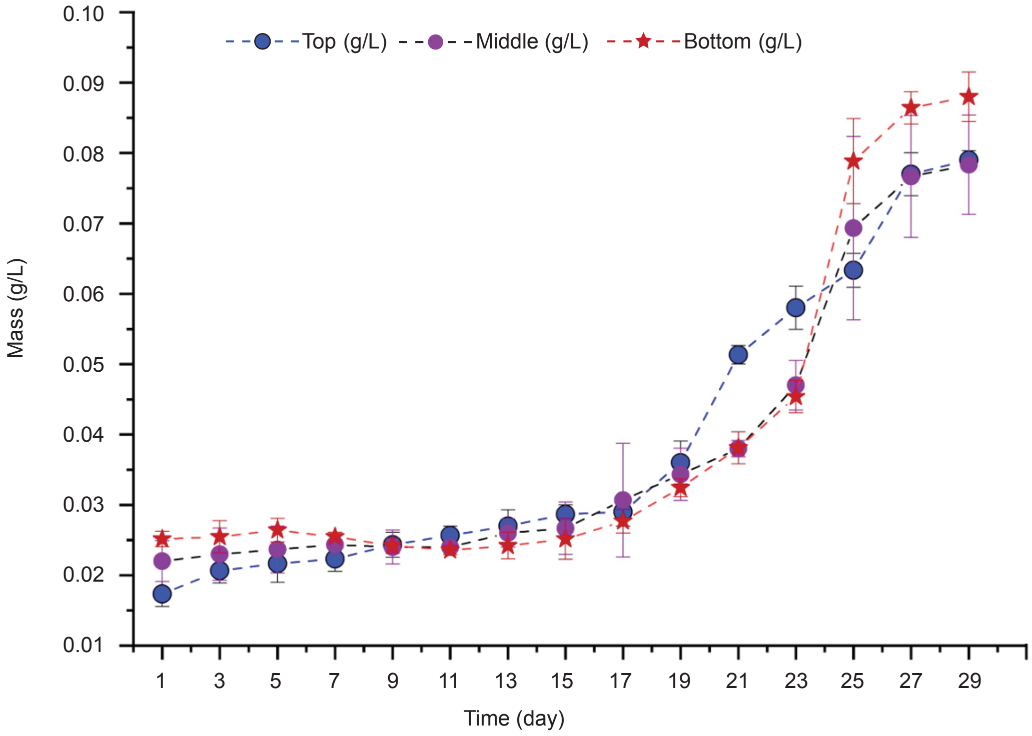

*Figure 3. Sediment formation test results.*

The test results for the average sediment formation after the mixing of fuels from the two sources in the ship's tanks are shown in *Figure 3* which indicates the mass of contaminants in each layer (top, middle and bottom) of the tank during storage. Under the initial conditions, the mass at the bottom of the tank was higher than that at the middle and top of the tank.

At the beginning of storage, a lower sediment mass was obtained at the top of the tank, namely, 0.016 g/L, this value was the lowest among the sections. Then, with storage time, there was an increase in sediment mass over 30 days of storage. At the top of the tank, the highest addition of sediment mass compared to the others occurred on Day 21, which was an increase of 0.016 g/L from the previous day. The total sediment from the top was less than that from the middle and bottom. In the middle tank, the highest increase occurred on Day 25 compared to the previous day of 0.028 g/L, with a sediment mass of 0.075. On the 25th day, there was a high degree of error compared to the other days, namely, 0.013. However, the error observed was still small. On Day 17 and Day 30, there was also a high degree of error in the middle of the tank, with errors of 0.0081 and 0.0087, respectively. At the bottom of the tank at the beginning of storage, the sediment mass was higher than that in the other sections, namely, 0.026 g/L. Based on the data, on the 25th day, there was a large difference in sediment mass at the bottom of the tank, with an average sediment concentration of 0.081 g/L and an error of 0.0024. Based on these results, most contaminants were located at the bottom of the tank, amounting to 0.621 g/L. The value at the top was 0.582 g/L and that in the middle of the tank was 0.588 g/L. These results are similar to results reported by Gozan *et al*. (2022) who noted that most contaminants are present at the bottom.

During fuel storage, there was an increase in the mass of contaminants, although there were some fluctuations. This occurred because ships at sea operate under unstable conditions and sea waves rock the ship so contaminants are re-suspended from the bottom of the tank, unlike during fuel storage on land or other stationary places. During the first 17 days, the ship was at port, then it began its sea voyage, and then the ship was at port again from the 25th day to the 30th day of storage. Based on this, the aggregation of contaminants occurs when the biodiesel is in a stationary state, and the presence of sea waves can help suppress the aggregation of contaminants. However, these results show an increase of approximately 312% in the mass of contaminants during the 30-day storage period.

## Morphology

This study evaluated sediment morphology to study sediment formation in the fuel storage tank of a ship. Morphological analysis was conducted with an optical microscope (HIROX KH-8700). Sample 1 has a different morphology than Sample 2, as shown in *Figure 4*. Sample 2 was found to exhibit small black particles that covered the sediment filter. These could be considered impurities that originated from diesel fuel, not biodiesel, as impurities in biodiesel mainly appear under low-temperature conditions (Paryanto *et al*., 2022). Asphaltene can be derived from marine fuel oil with a low H/C ratio, high aromatic content, and strong polarity (Zhou *et al*., 2023). Asphaltene can agglomerate with saturated monoglycerides of biodiesel due to the negative interaction energy between each component, increasing sediment formation from its agglomeration.

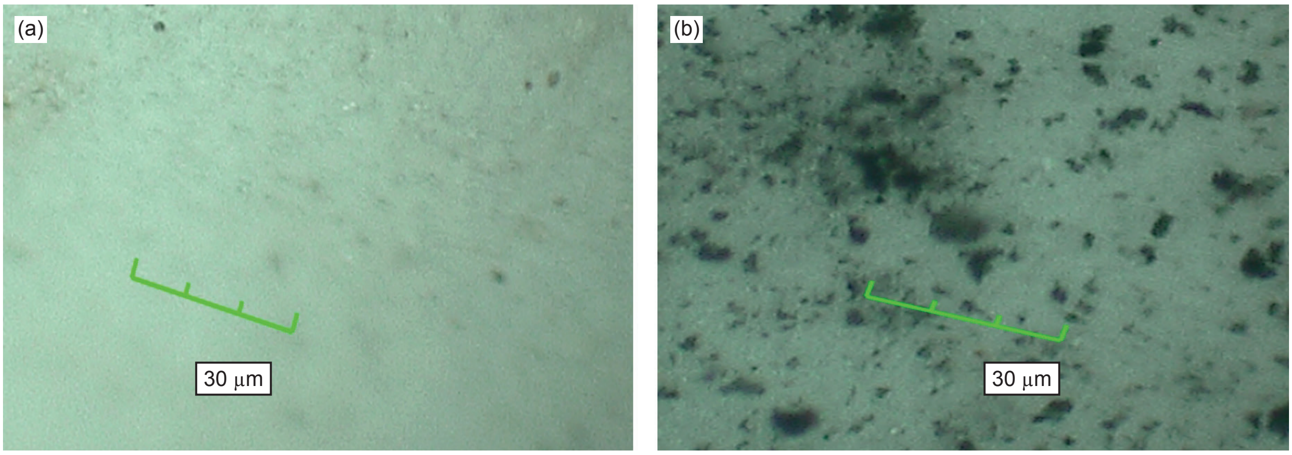

*Figure 4. Morphology of sediment formed in (a) Sample 1 and (b) Sample 2.*

*Figure 5* shows the granular form and sediment distribution across the filter media on the 10th, 25th, and 30th day after fuel sampling. The sediment on the 10th day exhibited small granular particles that covered the filter media, and more prominent granules were observed at several positions. Biodiesel sediment formation occurs mainly due to biodiesel's high saturated monoglyceride content, especially when the fuel is exposed to low-temperature environments below its cloud point. Furthermore, agglomerates continuously formed, developing into more prominent granules that covered the filter media, as shown in *Figure 5b*.

On the 30th day of fuel storage, more significant sediments could be observed covering the filter media. Here, agglomeration between asphaltene and biodiesel is indicated in black and this is considered the reason for the higher sediment content on the 30th day compared with the other days, as shown in *Figure 3*.

## Fourier Transform Infrared Spectroscopy (FTIR) Results

A spectrum of wavenumber (cm$^{-1}$) with percentage transmission (% T) was obtained with FTIR, with *Figure 6* showing the sample area based on the storage time of Sample 1, Sample 2, Sample 1+2 (1st day), Sample 1+2 (25th day) and Sample 1+2 (30th day).

This test was carried out to determine the functional groups present in the B30 biodiesel mixture with storage time. *Figure 6* shows the results of representative FTIR B30 spectra with storage time. *Figure 6* shows a type of mid-IR spectrum (400-4,000 cm$^{-1}$) that is divided into four regions: The first region is a single bond between 4,000-2,500 cm$^{-1}$, the second is a triple bond between 2,500-2,000 cm$^{-1}$, the third is a double bond between 2,000-1,500 cm$^{-1}$, and the fourth is the fingerprint bond region between 1,500-600 cm$^{-1}$. *Figure 6* shows six absorption peaks at 2,923, 2,849, 1,747, 1,463, 1,169 and 728 cm$^{-1}$. The visible peaks observed at 2,923 and 2,849 cm$^{-1}$ indicate saturated aliphatic hydrocarbons of methylene C-H, as shown in *Figure 6* (Coates, 2000), and are related to the stretching absorption of glyceride bonds of oleic, linoleic and palmitic acids (Ayoob & Fadhil, 2019). These peaks also corresponded to aromatic hydrocarbons, indicating asphaltene (Zhou *et al*., 2003).

*Figure 6* also clearly shows the presence of carbonyl functional groups, which are represented by the 1,747 cm$^{-1}$ and 1,169 cm$^{-1}$ peaks associated with the stretching of $CO_2$ double bonds (C-O) and $CO_2$ single bonds (C-O) (Dharma *et al*., 2016). An aliphatic methylene group with a C-H bond at wavenumber 1,463 cm$^{-1}$ can be attributed to $CH_3$ from lipids and COO- from amino acids (Ong & Nomanbhay, 2022). The wavenumber 722 cm$^{-1}$ is a *cis* double bond of a disubstituted olefin (Lim *et al*., 2018). The peak at 722 cm$^{-1}$ is associated with the bending of the C-C double bond. There was a decrease in spectral absorption at the peak 1,170 cm$^{-1}$. This condition indicates increased $CO_2$ stretching (Sebayang *et al*., 2023) at storage times of more than three weeks. Each line in *Figure 6* shows the same pattern with the wavenumbers and transmittance marked for C-H (2,700-3,000 cm$^{-1}$), C=O (1,500-1,800 cm$^{-1}$) and C-O (600-1,400 cm$^{-1}$). The ester molecule (palm biodiesel) is visible in the C-O and C=O spectra. There is no reaction due to free radicals because there is no -O-H chain in the figure (*Figure 6*), which implies a reduced oxygen level. This is supported by the presence of substantial (73%) -C-H (2,923 cm$^{-1}$) and weak -O-H bonds (98%).

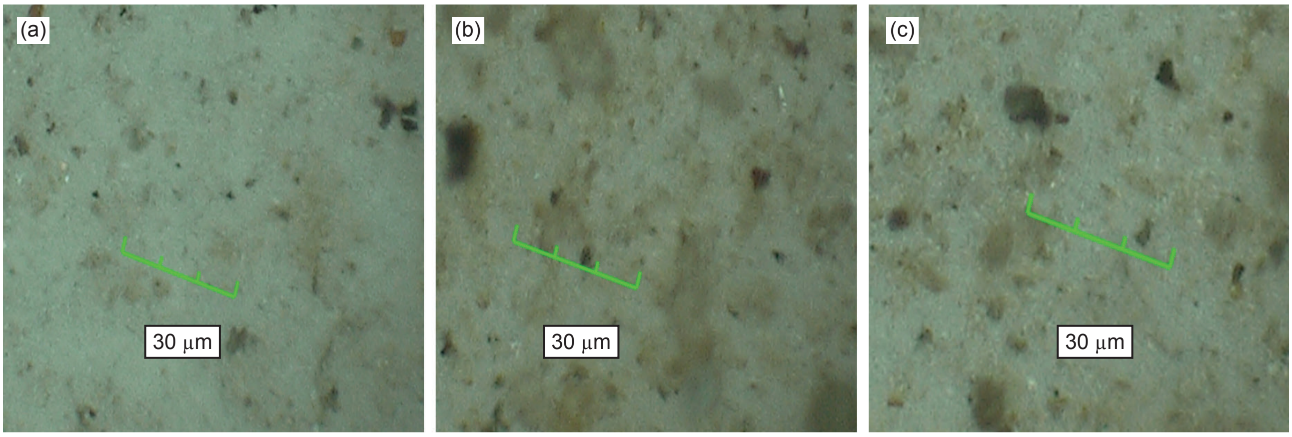

*Figure 5*. *Morphology of sediment formed on the (a) 10th day, (b) 25th day, and (c) 30th day of mixed fuel storage.*

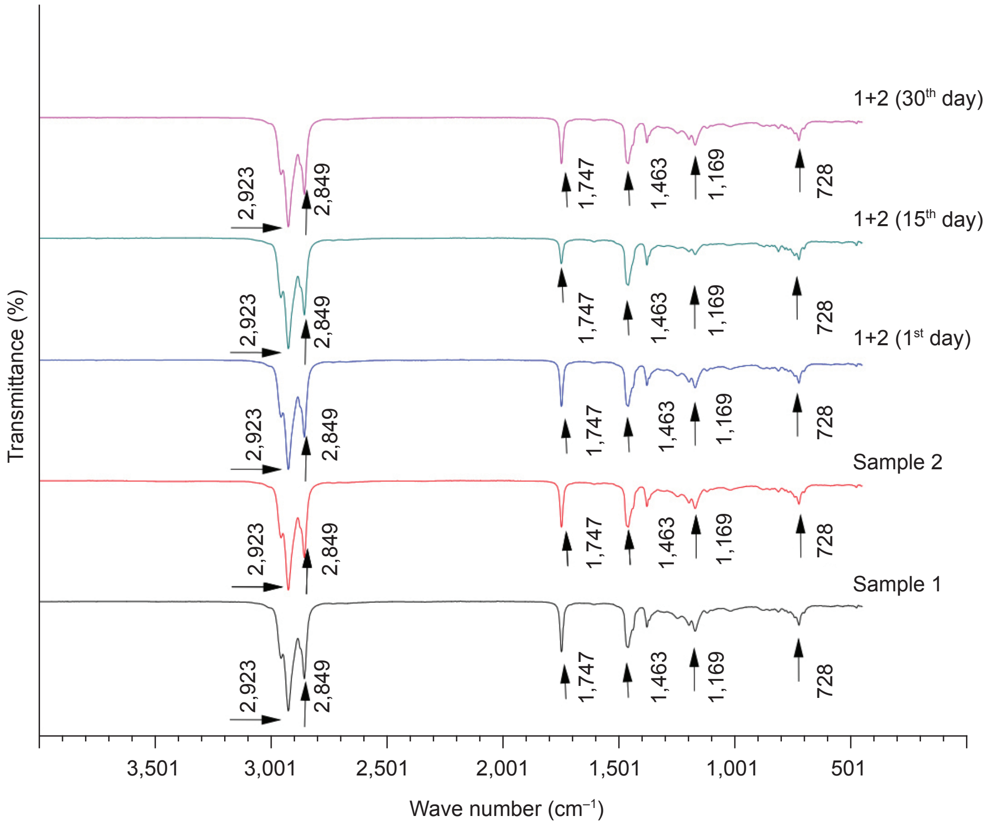

*Figure 6. FTIR results.*

## CONCLUSION

In this study, tests on the characteristics of biodiesel B30 were carried out, including its cleanliness, viscosity, density, and water content. The results of this study show that differences in biodiesel sources affect these characteristics. In addition, the length of storage time plays a role in changing these characteristics. The results of the sediment test for biodiesel-diesel mixtures stored in ship tanks under actual conditions demonstrated the formation of contaminants with storage time. Based on the sediment test results, contaminants significantly increased after storage times longer than 20 days. This study showed an unstable distribution of contaminants between the bottom, middle and top of the ship's tank. These results indicate that fuel properties are unstable when the fuel is stored in a ship's tank in contrast to its storage in stationary fuel tanks, such as on land, where most contaminants remain at the bottom of the tank. The length of storage time is very influential on the formation of contaminants and it can be seen that there is an increase in contaminants after three weeks of storage. This condition dramatically affects the strategy for handling biodiesel blend storage in ship tanks. In addition, the quality of the biodiesel fuel mixture from the filling source is of particular concern during tank filling, as the blended fuel deteriorates as the storage period increases.

The interaction of asphaltene with water and other sediments, the prediction of sediment accumulation in a ship's fuel tank, the determination of the tank cleaning period, and detailed influences of various factors, such as multiple biodiesel properties, should be further studied to obtain better knowledge of the formation of contaminants. Sediment composition must be studied in greater detail in future studies to find countermeasures to sediment formation.

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