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COMPATIBILITY OF TERNE SHEET WITH PALM BIODIESEL BLENDS

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ABSTRACT

The quality of biodiesel blends and its compatibility with fuel tank materials needs to be investigated before any higher biodiesel blends are introduced. This is to ensure that there are no leaching of any undesired materials which may degrade or oxidise the fuel and ultimately cause failure to vehicles. This article discusses the oxidation stability of palm biodiesel and its blends with petroleum diesel, i.e. *B7, B10 and B15. The effect of palm biodiesel and its blends on terne sheet were examined using cup test. Terne sheet, a material commonly used to fabricate automotive fuel tanks, has been previously identified as incompatible with biodiesel. Nevertheless, the findings showed that palm biodiesel blends would not cause any corrosion or incompatibility with terne sheet. The terne plating was maintained at approximately 40 g m*$^{-2}$ *after exposure to palm biodiesel and its blends at 80°C for 1000 hr. Scanning electron microscopy (SEM) morphologies have shown no signs of corrosion or pitting on the surface of the terne plating. No leaching of heavy metals was found on the fuel samples. Hence, the terne sheet was found compatible with palm biodiesel blends as long as the test fuels in use were of good quality.*

Keywords: material compatibility, oxidation stability, palm biodiesel, terne sheet.

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INTRODUCTION

Biodiesel is defined as a fuel comprised of mono-alkyl esters of long chain fatty acids (ASTM International, 2015). It can be derived from either vegetable oils or animal fats. Biodiesel is a product of transesterification process in which the said feedstocks are reacted with methanol in the presence of a base catalyst (Clark *et al.*, 1984; Ali *et al.*, 1995; Choo *et al.*, 1995; Chang *et al.*, 1996; Cvengros *et al.*, 1999; Mittelbach and Enzelsberger, 1999). The raw materials used for the production of biodiesel vary dependant on locations. Soyabean oil is typically used in the United States and Argentina, whereas rapeseed oil is common in the European continent. In South-east Asia, palm oil is the most widely used oil (Kushairi *et at.*, 2017).

Biodiesel is designated as B100 whereas its blends with petroleum diesel are designated as BX, where X is the vol% of biodiesel in petroleum diesel (ASTM International, 2015). Biodiesel blends have been commercially used in many countries for more than a decade. The biodiesel programme with <7% biodiesel (B<7) was implemented in Europe particularly in Germany, France, United Kingdom, the Netherlands, *etc*. In the United States, the biodiesel blends, *i.e.* B5, B10 and B20 were supplied to retail stations on a voluntary basis (Tang *et al.*, 2008; Guzman *et al.*, 2010; Alleman *et al.*, 2011). In South-east Asia, Indonesia mandated to use B20 while Malaysia and Thailand B7 and B5 in the Philippines. The B5 blend was first introduced to retail stations in different regions of Peninsular

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Malaysia in stages since mid-2011 (Yung *et al.*, 2016). In November 2014, the B5 was replaced by B7. The B7 programme was further expanded to Sabah and Sarawak in December 2014. This marked the nationwide B7 implementation in the country.

The use of higher biodiesel blends (>7 vol%) is of great concern because of the stability and compatibility with the engine or fuel tank materials. Various studies have been conducted showing both positive and negative effects of biodiesel (pure form and blended) on various metallic components. The results were summarised in *Table 1*.

Tsuchiya *et al.* (2006) studied the corrosion effect of biodiesel blends (B0-B5) using the cup test method. They discovered that B2 corroded the terne cup specimen and the corrosion was due to the formation of short chain organic acids in the degraded biodiesel blends. In the fuel circulation test, the fuel tank which was exposed to biodiesel blends with sufficient oxidation stability, *i.e.* 9.6 hr Rancimat induction period (IP) was found corrosion free. The plating residual quantity of fuel tank made of terne sheet remained at about 40 g m^{-2}. It was concluded that three important parameters of biodiesel blends, *i.e.* oxidation stability, acid number (AN) and organic acids concentration would determine the corrosion of metallic materials. They concluded the limit of (1) AN of 0.13 mg KOH g^{-1} (max) and (2) total organic acids concentration of 30 ppm (max) must be regulated to prevent corrosion on metal components, in particular, the fuel tank.

Kaul *et al.* (2007) conducted the static immersion test for piston metal and piston liner at an ambient temperature that ranged from 15°C to 40°C for 300 days. The study showed no corrosion to the piston metal and piston liner for Mahua and Karanja biodiesels, but *vice versa* for Salvadora biodiesel possibly due to a much higher sulphur content of 1200 ppm. The Jatropha biodiesel showed slight effects on the piston liner. All four types of biodiesel degraded significantly after the test. There was a drastic change of AN from 0.4 mg KOH g^{-1} to 11-19 mg KOH g^{-1} for Jatropha, Mahua and Karanja biodiesel, while that of Salvadora biodiesel increased from 0.45 mg KOH g^{-1} to 2.3-2.5 mg KOH g^{-1}.

Haseeb *et al.* (2010) studied the corrosion behaviour of petroleum diesel and palm biodiesel on coupons made of copper and leaded bronze. The corrosion rates in copper were found higher than in leaded bronze at room temperature (25°C-30°C) and 60°C. The corrosion rates were higher at 60°C compared to room temperature. The AN of palm biodiesel had doubled to 1 mg KOH g^{-1} upon storage at room temperature for 2640 hr. However, no significant changes in AN were observed for petroleum diesel.

Fazal *et al.* (2010; 2011a, b; 2012) carried out studies on the corrosive effects of palm biodiesel and petroleum diesel on various metallic coupons including copper, aluminium, stainless steel, cast iron, mild steel and brass. Copper and aluminium were found susceptible to corrosion by both the palm biodiesel and petroleum diesel, and were detected in the fuels upon storage at 80°C for 1200 hr (Fazal *et al.*, 2010). However, stainless steel was found free from corrosion. Significant pits were observed on the scanning electron microscopy (SEM) images of copper specimens. The AN of palm biodiesel exposed to these specimens increased four-fold from 0.35 to >1.5 mg KOH g^{-1}, even for stainless steel which was found to be compatible with biodiesel. Although tertbutyl amine can be an effective corrosion inhibitor for palm biodiesel, it has no effect on the AN of the biodiesel samples exposed to cast iron at room temperature for 1200 hr as the value has doubled to 1 mg KOH g^{-1} (Fazal *et al.*, 2011a). Similar to copper and leaded bronze, the corrosion rate on mild steel increased at elevated temperatures of 50°C and 80°C (Fazal *et al.*, 2011b). The AN of palm biodiesel exposed to mild steel has increased to 2 mg KOH g^{-1} upon storage at the elevated temperatures for 1200 hr. Interestingly, the AN of palm biodiesel stored at 80°C even without mild steel exposure has also increased to 1.5 mg KOH g^{-1}. This suggested that the degradation of palm biodiesel was accelerated by both the elevated temperature and the presence of mild steel. The copper and brass corrosion rates were higher compared to aluminium and cast iron (Fazal *et al.*, 2012).

Hu *et al.* (2012) examined metals exposure to rapeseed biodiesel at 43°C for 60 days. They found the copper and mild carbon steel exhibited more significant corrosion effects than aluminium and stainless steel. The atomic absorption spectrometry results showed the increase of copper and iron concentrations for the biodiesel exposed to copper, mild carbon steel and stainless steel, respectively.

Japan Petroleum Energy Centre (JPEC) (2012) investigated the material compatibility of soyabean oil biodiesel on various materials using similar cup test approach as demonstrated by Tsuchiya *et al.* (2006). The materials studied including terne sheet, bonderised steel, tin galvanised steel sheet and hot-dipped aluminium-coated steel sheet. Pitting was observed on the surfaces of terne test cups exposed to biodiesel. Lead was detected in B20, B50 and B100 at the end of the test. This indicated elution of terne plating from steel sheet to the tested fuels.

Kovacs *et al.* (2015) evaluated the storage and corrosion characteristic of biodiesel sampled from an operational tank dedicated for automotive fuel blending facility in Hungary. The biodiesel sample met key properties stipulated in the European Standard EN 14214 with Rancimat IP >6 hr. The corrosion tests performed revealed that although the AN of biodiesel samples exposed to carbon steel coupons at 35°C for 120 days had slightly

TABLE 1. SUMMARY OF METALLIC MATERIALS COMPATIBILITY TEST FOR BIODIESEL

Test fuel	Material tested	Testing conditions	Corrosion/pitting	Reference
B0-B5 (biodiesel with acid number ~0.5 mg KOH g^{-1})	Terne sheet	Terne cup test. 80°C, 1 000 hr.	Corrosion on terne cup by B2. Lead detected in fuel samples after soaking.	Tsuchiya *et al*. (2006)
B5 (palm/rapeseed/soyabean biodiesel: 60/36/4) blend with JIS No. 2 diesel: (a) B5 with added antioxidant (20 ppm). (b) B5 with added acids (27 ppm acetic acid, 525 ppm oleic acid). (c) B5 with added acids and antioxidant.	Terne sheet, bonde steel.	Fuel circulation test. Room temperature - 60°C, 2 000 hr.	No corrosion for B5(a). Corrosion for B5(b) & B5(c).	Tsuchiya *et al*. (2006)
Biodiesel: (a) Mahua (b) Salvadora (c) Pongamia (d) Jatropha	Piston metal, piston liner	Static immersion test, 15°C-40°C, 300 days.	No corrosion for Mahua and Karanja biodiesel. Corrosion for Salvadora biodiesel. Slight corrosion on piston liner for Jatropha biodiesel.	Kaul *et al*. (2007)
B0, B50 and B100 (palm biodiesel)	Copper, leaded bronze	Static immersion test, room temperature (25°C -30°C) for 2640 hr and 60°C for 840 hr.	Pitting for copper exposed to B100 at 60°C.	Haseeb *et al*. (2010)
B0 and B100 (palm biodiesel)	Aluminium, copper, stainless steel	Static immersion test, . 80°C, 1 200 hr	Corrosion/pitting for copper and aluminium exposed to B0 and B100. No corrosion for stainless steel.	Fazal *et al*. (2010)
B100 (palm biodiesel) with and without corrision inhibitors	Cast iron	Static immersion test, room temperature, 1 200 hr.	Corrosion for cast iron exposed to biodiesel with and without corrosion inhibitor. Less corrosion for cast iron exposed to tert-butyl amine added palm biodiesel.	Fazal *et al*. (2011a)
B0, B50 and B100 (palm biodiesel)	Mild steel	Static immersion test, room temperature (27°C), 50°C & 80°C, 1 200 hr.	Corrosion for B0 and B100. Less corrosion for diesel compared with biodiesel.	Fazal *et al*. (2011b)
B0 and B100 (palm biodiesel)	Copper, brass, aluminium, cast iron	Static immersion, room temperature (25°C-27°C), 2 880 hr.	Corrosion for B0 and B100. Less corrosion for diesel compared with biodiesel.	Fazal *et al*. (2012)
Rapeseed biodiesel	Copper, mild carbon steel, aluminium, stainless steel	Static immersion, 43°C, 60 days.	Severe corrosion for copper and mild carbon steel Minor corrosion for aluminium and stainless steel.	Hu *et al*. (2012)

TABLE 1. SUMMARY OF METALLIC MATERIALS COMPATIBILITY TEST FOR BIODIESEL (continued)

Test fuel	Material tested	Testing conditions	Corrosion/pitting	Reference
B0, B10, B20, B50 & B100 (soyabean methyl ester)	Terne sheet, bonderised steel, tin galvanised steel sheet, hot dip aluminium coated steel	Cup test, 80°C, 1 000 hr	Decrease in mass for terne sheet exposed to all test fuel. Decrease in mass for tin galvanised steel exposed to B50 and B100. Dissolution of surface material and exposure of base metal exposed to B100. Pitting observed on cup surface exposed to B100.	Japan Petroleum Energy Centre (2012)
Biodiesel, met EN 14214 with oxidation stability >6 hr	Carbon steel	Static immersion, 20°C and 35°C, 120 days	No corrosion Acid number of biodiesel samples significantly below ceiling value of 0.5 mg KOH g^{-1}	Kovacs *et al.* (2015)

increased to 0.21 mg KOH g^{-1}, it was still well below the ceiling value of 0.5 mg KOH g^{-1}. No significant corrosion was observed on carbon steel coupons. They concluded that no corrosion would occur for biodiesel stored under typical storage conditions and the stability can be retained for 120 days.

In this study, the terne cup test was conducted to evaluate the terne sheet compatibility for the commercially obtained palm biodiesel and its blends with petroleum diesel. Terne sheet is a steel sheet coated with a lead-tin alloy with superior corrosion resistance in the hot dipping process. It is a common material used to fabricate fuel tanks for diesel vehicles in the South-east Asia market. The effects of palm biodiesel blend with blending ratio <20 vol% on terne sheet was investigated according to the methodology by Tsuchiya *et al.* (2006) and JPEC (2012), a methodology recognised by the automakers, in particular, the Japanese Automobile Manufacturers Association (JAMA).

MATERIALS AND METHODS

Materials

Two types of petroleum diesel (Euro 2M and Euro 5) were obtained from Malaysian diesel suppliers. Palm biodiesel was obtained locally from a palm biodiesel producer. Both the petroleum diesel and palm biodiesel complied fully with the relevant local diesel (MS123-1:2014, MS123-3:2016) and biodiesel (MS2008:2014) standard specifications respectively (Department of Standards Malaysia, 2014a, b; 2016). Test cups made of terne sheet with a dimension of 50 mm internal diameter and 35 mm depth were used in this study.

Methods

The biodiesel blends (B7, B10 and B15) were prepared by blending palm biodiesel with petroleum diesel according to the stated vol%. The fuel samples were analysed for oxidation stability using both the Rancimat (EN 15751) and the PetroOXY (ASTM D7545) methods.

Material compatibility study was conducted using test cups made of terne sheet. The 40 ml of each fuel sample was filled into a test cup. The test cups were sealed with glass covers and tightened with clamps, then stored at 80°C for 1000 hr. The tested fuel samples were exchanged with fresh samples every 250 hr. The test was triplicated for every fuel sample. The appearances of the cups were examined and photographs were taken during every change of the fuel samples.

The heated fuel samples were analysed for organic acids content, metal contents and AN. Organic acids content was determined using a

Dionex Ion Chromatograph ICS-90 equipped with an IonPac ICE-AS1 column (9 mm x 250 mm) according to JIS K 0127. The eluent was 1.0 mmol litre^{-1} octane sulphonic acid with a flow rate of 1.0 ml min^{-1}. Samples injection volume was set at 50 µl. The leached metals, if any, were determined using a Varian ICP 720-ES according to JIS K 0116. The AN was analysed according to ASTM D664 using a Hiranuma Potentiometric Autotitrator COM-1700.

After 1000 hr physical contact with test fuels, the test cup specimens were examined for any residual amount of plating using X-ray fluorescence method. Results were compared with cup specimen which was not exposed to any fuel sample. The surface morphology of terne plating on the test cups was examined and analysed using a SEM with energy dispersive X-ray spectroscopy (SEM-EDX).

Analysis of Petroleum Diesel and Palm Biodiesel

Prior to the compatibility test, the petroleum diesel and palm biodiesel were analysed for their fuel properties according to standard test methods, as in *Tables 2* and *3*.

RESULTS AND DISCUSSION

The properties of both the Euro 2M and Euro 5 petroleum diesel fuels used in this study are shown in *Table 2*. The significant difference between these two diesel fuels is the sulphur content. The maximum limits set are 500 mg kg^{-1} and 10 mg kg^{-1} for the Euro 2M and Euro 5, respectively (Department of Standards Malaysia, 2014a; 2016).

TABLE 2. PROPERTIES OF EURO 2M AND EURO 5 PETROLEUM DIESEL

Property	Test method	Unit	Euro 2M	Euro 5
ASTM colour	ASTM D1500	-	L0.5	L0.5
Ash	ASTM D482	mass %	<0.001	<0.001
Cloud point	ASTM D2500	°C	-8	-8
Kinematic viscosity at 40°C	ASTM D445	mm^2 s^{-1}	3.7876	3.0138
Copper corrosion (3 hr at 50°C)	ASTM D130	Rating	1a	1a
Water	EN ISO 12937	mg kg^{-1}	93	78
Sediment by extraction	ASTM D473	mass %	<0.01	<0.01
Carbon residue on 10% bottom	ASTM D189	mass %	<0.10	<0.10
Density at 15°C	ASTM D4052	g ml^{-1}	0.8575	0.8371
Acid number	ASTM D664	mg KOH g^{-1}	0.03	0.02
Electrical conductivity	ASTM D2624	pS m^{-1}	830	534
Derived cetane number	ASTM D6890	-	53.4	54.2
Lubricity	ASTM D6079	µm	372.5	402.5
Total sulphur	ASTM D5453	mg kg^{-1}	384	5.1

TABLE 3. PROPERTIES OF PALM BIODIESEL

Property	Test method	Unit	Palm biodiesel
Density at 15°C	EN ISO 12185	kg m^{-3}	875.4
Kinematic viscosity at 40°C	EN ISO 3104	mm^2 s^{-1}	4.5059
Flash point	ASTM D93	°C	170.5
Water	EN ISO 12937	mg kg^{-1}	306
Total contamination	EN 12662	mg kg^{-1}	<6
Copper corrosion (3 hr at 50°C)	EN ISO 2160	rating	1a
Oxidation stability	EN 15751	hr	16.9
Acid value	EN 14104	mg KOH g^{-1}	0.35
FAME content	EN 14103	mass %	98.5
Linolenic acid methyl ester	EN 14103	mass %	0.2
Methanol	EN 14110	mass %	<0.01
Monoglyceride	EN 14105	mass %	0.39
Diglyceride	EN 14105	mass %	0.09
Triglyceride	EN 14105	mass %	0.02
Free glycerol	EN 14105	mass %	0.011
Total glycerol	EN 14105	mass %	0.124
Group I metals (Na+K)	EN 14538	mg kg^{-1}	4.2
Group II metals (Ca+Mg)	EN 14538	mg kg^{-1}	<1
Phosphorus	EN 14107	mg kg^{-1}	<1
Sulphur	ASTM D5453	mg kg^{-1}	1.4
Cold filter plugging point	EN 116	°C	13

The typical properties of palm biodiesel used for blending with petroleum diesel in Malaysia are shown in *Table 3*.

In general, palm biodiesel has lower Rancimat stability compared to petroleum diesel, as shown in *Figure 1*. The IP of the Euro 2M and Euro 5 diesel fuels measured using the Rancimat and PetroOXY methods were 7 and 2 times higher than palm biodiesel. Even without blending, the IP of palm biodiesel was 16.9 hr, which exceeds the minimum 10 hr required by the Malaysian Standard (MS2008:2014) (Department of Standards Malaysia, 2014b). As reported previously, palm biodiesel produced from the refined, bleached and deodourised palm oil possesses superior oxidation stability. This is because the naturally inherited fatty acid compositions in the oil and its natural antioxidants remained intact even after it is processed into biodiesel (Yung *et al*., 2013). Blending palm biodiesel with lower oxidation stability into petroleum diesel would naturally reduce the overall stability of the blends, *e.g.* from the IP of 112.7 hr down to 87.0 hr and 78.0 hr, respectively for both the B10 and B15 of the Euro 2M diesel blends. However, these IP values were still higher than the required 20 hr stipulated by the European Standard Specification for B10, B20 and B30 (The British Standards Institution, 2015; 2016). In pure form, Euro 5 diesel has a much lower Rancimat stability than Euro 2M diesel. Hence, the B10 and B15 of the Euro 5 diesel blends showed lower IP of 32.4 hr and 29.4 hr. These values had still exceeded the requirement by the European Standards but were slightly lower than the minimum 35 hr required by the Worldwide Fuel Charter (ACEA *et al*., 2013).

Similar stability trends were observed for the palm biodiesel blends tested via PetroOXY. The IP of the Euro 2M B10 and Euro 5 B10 diesel blends were 239 min and 92 min, *i.e.* 1-4 times higher than the recommended 65 min minimum limit. As shown in *Figure 1*, the Rancimat stability results correlated well with the PetroOXY stability results with an R^2 value of 0.99.

The concentrations of organic acids, *i.e.* formic acid, acetic acid and propionic acid in all the palm biodiesel blends were well below 30 ppm (*Table 4*), the maximum value specified by the Japanese Quality Assurance Law Specification. According to Tsuchiya *et al.* (2006), the formation of organic acids is a sign of fuel degradation and corrosion of fuel tank may occur once the value exceeds 30 ppm. The organic acids formed tend to attack the metallic components of the fuel tank and which forms metallic salts and ultimately cause adverse effects to the fuel injectors of a vehicle (Goto *et al*., 2010). Again, as the neat palm biodiesel was more susceptible to oxidation (with lower IP), the presence of formic acid and acetic acid becomes significant after 250 hr storage period.

The AN of palm biodiesel blends (B7, B10 and B15) showed very minimal increase upon accelerated oxidation at 80°C for 1000 hr (*Table 5*). This finding was similar to those reported by Kovacs *et al.* (2015). All the AN values of palm biodiesel blends complied with the allowable limits of 0.13 and 0.25 mg KOH g^{-1} set by both the Japanese and Malaysian Standards. Even the AN of the neat palm biodiesel after 1000 hr storage was below the limit of 0.5 mg KOH g^{-1}.

The appearances of test cups after 1000 hr with direct exposure to test fuels are shown in *Figures 2* and *3*. Optical observations showed no physical trace of corrosion for all the specimens inspected, including cup specimens exposed to the neat palm biodiesel. The X-ray fluorescence results (*Table 6*) concurred with the optical inspection. The amount of terne plating for cup specimens exposed to all the palm biodiesel blends was quite similar, 40 g m^{-2} on average. In addition, *Table 7* showed that there were hardly any leached metals into the palm biodiesel blends at storage at 80°C. The SEM-EDX analysis showed that only lead and tin were detected on the surface of all the cup specimens. There were no significant differences among all the cup specimens directly in contact with the neat diesel, palm biodiesel and its blends, with the blank cup (*Figures 4* and *5*). All the SEM images showed equal plating surfaces without corrosion or pitting. This showed that there was hardly any terne plating deterioration in the test cups during storage, and thus the palm biodiesel blends behaved similarly to the blank cup without exposure to any diesel fuel and those filled with neat palm biodiesel. These results were distinctively different from those obtained previously by Tsuchiya *et al.* (2006) and JPEC (2012), which mainly attributed to the different sources of biodiesel and petroleum diesel used. In this study, the commercial palm biodiesel used had Rancimat stability exceeded 10 hr whereas JPEC (2012) used less stable soyabean oil biodiesel. On top of that, the commercial petroleum diesel, *i.e.* Euro 2M and Euro 5 used were also much superior compared to the less stable ones used in other studies.

CONCLUSION

This study showed that palm biodiesel and its blends with petroleum diesel (B7, B10 and B15) possessed superior oxidation stability. Inspection and observation on the side walls of the test cups exposed to palm biodiesel and its blends at elevated temperature (80°C) showed no corrosion and pitting. The tested terne sheet was highly compatible with the neat palm biodiesel and its blends with petroleum diesel up to 15 vol%. The terne sheet was found compatible with palm biodiesel blends as long as the test fuels in use were of good quality.

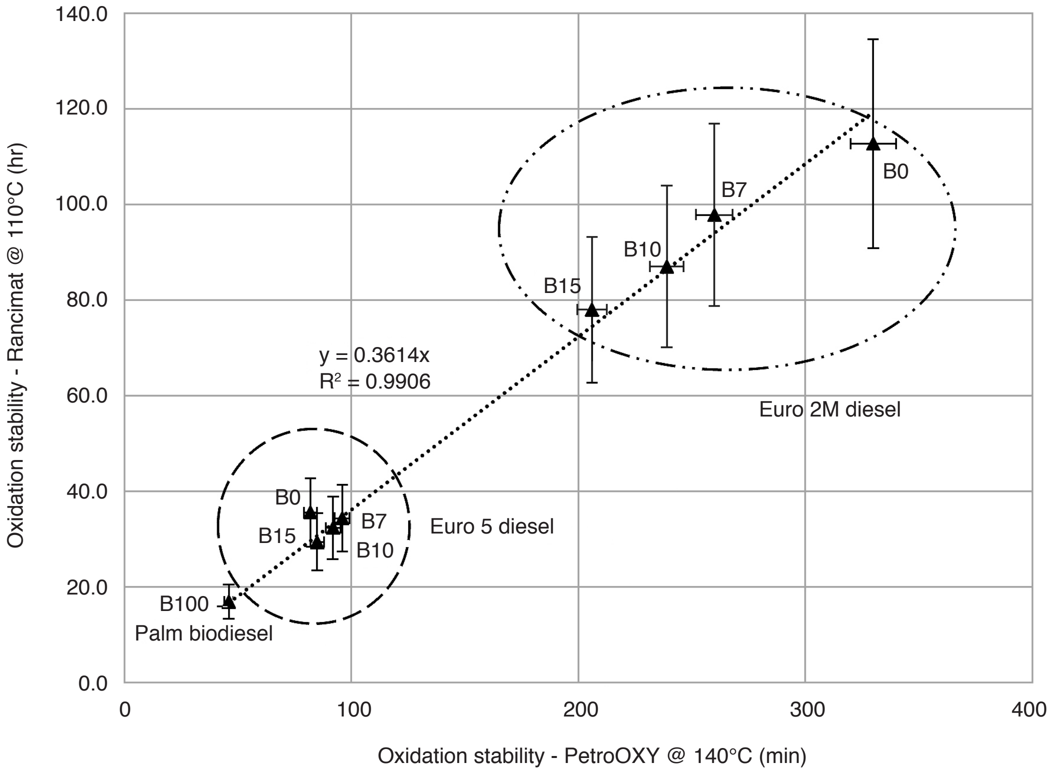

Figure 1. The induction periods of palm biodiesel blends via the Rancimat and PetroOXY tests. R = 0.37269 + 0.19038X for Rancimat. R = 0.0863X +1.3772 for PetroOXY.

TABLE 4. ORGANIC ACIDS CONTENTS OF PALM BIODIESEL BLENDS AFTER THE TERNE CUP TEST AT ELEVATED TEMPERATURE (80°C)

Fuel	Formic acid (ppm)			Acetic acid (ppm)			Propionic acid (ppm)		
	0 hr	250 hr	1 000 hr	0 hr	250 hr	1 000 hr	0 hr	250 hr	1 000 hr
Euro 2M diesel (B0)	0.8	1.3	1.2	<0.3	2.1	1.3	<0.3	0.3	<0.3
Euro 2M B7	1.0	1.4	1.4	0.5	3.3	2.2	<0.3	0.4	<0.3
Euro 2M B10	1.2	1.6	1.5	0.7	1.8	1.9	<0.3	<0.3	0.3
Euro 2M B15	0.9	3.3	1.8	0.6	4.0	2.9	<0.3	0.6	0.5
Euro 5 diesel (B0)	0.8	1.6	1.1	<0.3	2.1	0.5	<0.3	0.3	<0.3
Euro 5 B7	1.0	1.4	1.5	0.5	1.4	0.9	<0.3	<0.3	<0.3
Euro 5 B10	1.2	1.7	1.8	0.5	2.5	2.1	<0.3	0.6	0.3
Euro 5 B15	1.2	2.3	3.6	0.6	7.6	4.9	<0.3	0.7	0.5
Palm biodiesel (B100)	2.2	7.2	19.0	1.9	35.0	54.0	0.3	1.1	1.4

TABLE 5. ACID NUMBERS (AN) OF PALM BIODIESEL BLENDS AFTER THE TERNE CUP TEST AT ELEVATED TEMPERATURE (80°C)

Fuel	Storage period (hr)				
	0	250	500	750	1 000
Euro 2M diesel (B0)	0.03	0.04	0.02	0.04	0.03
Euro 2M B7	0.05	0.05	0.06	0.06	0.06
Euro 2M B10	0.06	0.06	0.07	0.07	0.07
Euro 2M B15	0.08	0.09	0.08	0.09	0.09
Euro 5 diesel (B0)	0.02	0.03	0.02	0.02	0.02
Euro 5 B7	0.04	0.03	0.04	0.04	0.03
Euro 5 B10	0.05	0.05	0.05	0.05	0.05
Euro 5 B15	0.06	0.07	0.07	0.06	0.06
Palm biodiesel (B100)	0.35	0.42	0.44	0.46	0.45

TABLE 6. THE AMOUNT OF TERNE PLATING OF SPECIMENS AFTER THE TERNE CUP TEST AT ELEVATED TEMPERATURE (80°C)

Fuel	Residual amount of plating (g m^{-2})
Euro 2M diesel (B0)	40
Euro 2M B7	40
Euro 2M B10	45
Euro 2M B15	42
Euro 5 diesel (B0)	46
Euro 5 B7	42
Euro 5 B10	45
Euro 5 B15	41
Palm biodiesel (B100)	43
Blank	42

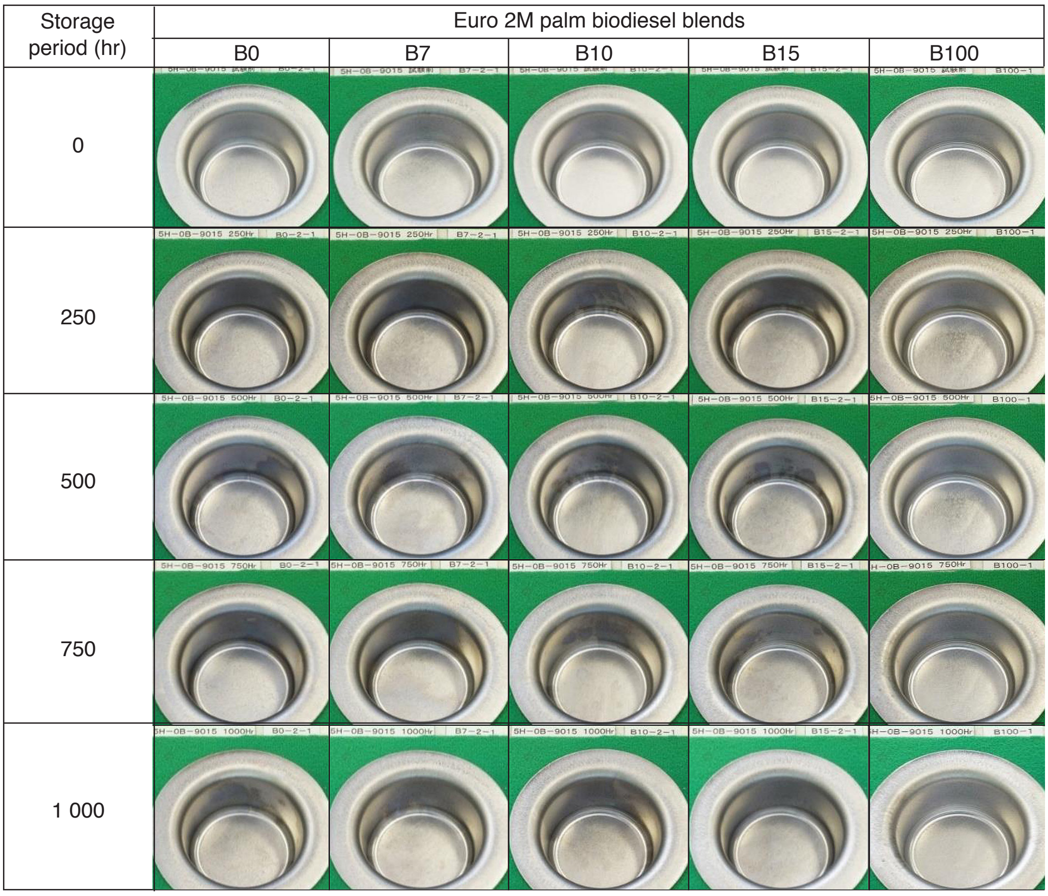

Figure 2. Appearances of test cups after exposed to Euro 2M palm biodiesel blends.

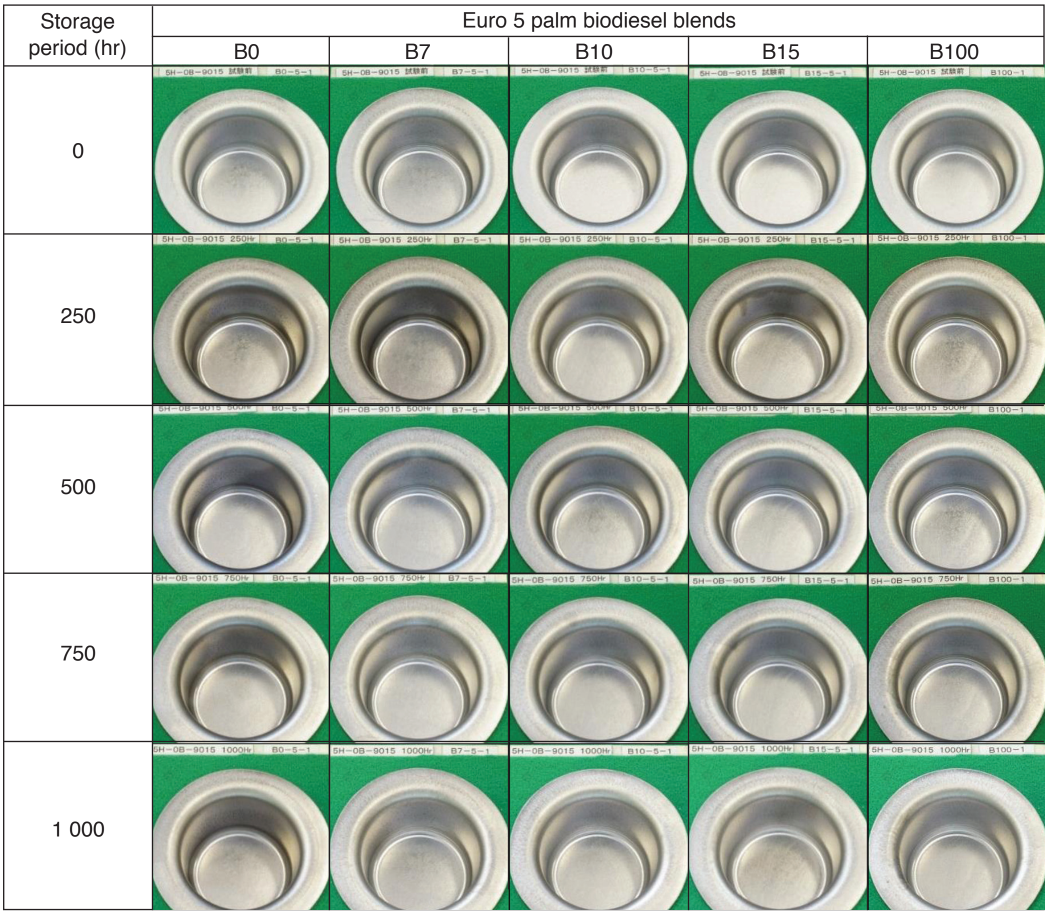

Figure 3. Appearances of test cups after exposed to Euro 5 palm biodiesel blends.

TABLE 7. THE LEACHED METALS IN PALM BIODIESEL BLENDS AFTER THE TERNE CUP TEST AT ELEVATED TEMPERATURE (80°C)

Fuel	Pb (ppm)					Sn (ppm)					Ni (ppm)					Fe (ppm)				
	0 hr	250 hr	500 hr	750 hr	1 000 hr	0 hr	250 hr	500 hr	750 hr	1 000 hr	0 hr	250 hr	500 hr	750 hr	1 000 hr	0 hr	250 hr	500 hr	750 hr	1 000 hr
Euro 2M diesel (B0)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 2M B7	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 2M B 10	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 2M B 15	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 5 diesel (B0)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 5 B7	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 5 B10	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Euro 5 B15	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Palm biodiesel (B100)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3

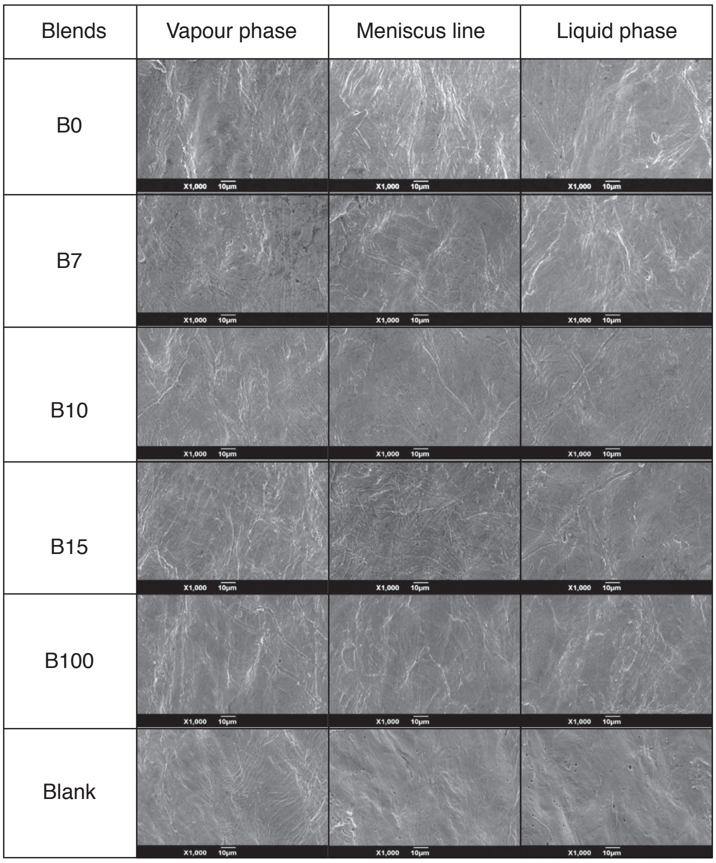

Figure 4. Scanning electron microscopy (SEM) images showing plating surfaces of test cups after exposed to Euro 2M palm biodiesel blends.

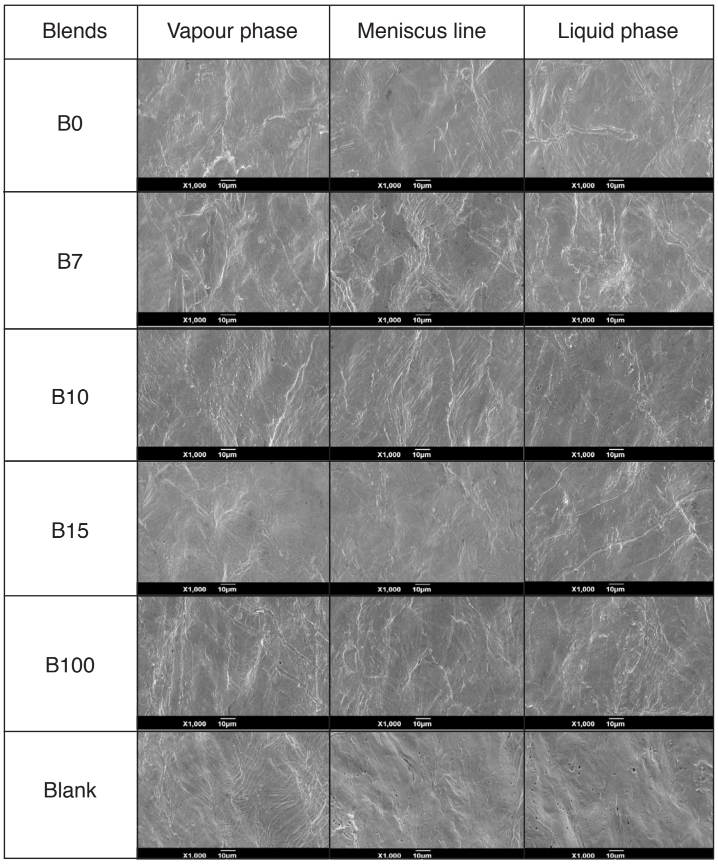

Figure 5. Scanning electron microscopy (SEM) images showing plating surfaces of test cups after exposed to Euro 5 palm biodiesel blends.

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