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MALAYSIAN B5 IMPLEMENTATION AND ITS QUALITY

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ABSTRACT

A quality survey of 80 samples of diesel fuels (B5) from 80 retail stations throughout Peninsular Malaysia was performed. The biodiesel contents in these B5 samples were in the range of 4.61 vol. % to 5.33 vol.%. The water contents of the samples were <200 mg kg^{-1}, meeting the stringent water requirements recommended by the car manufacturers. In addition, all the samples exhibited superior lubricity as indicated by a much shorter wear scar diameter compared to neat diesel. More importantly, 98% of the samples passed the oxidation stability test (PetroOXY) with an induction period of >65 min. Overall, the B5 diesel fuel sold was in full compliance with the Malaysian diesel fuel standard specification.

Keywords: diesel fuel, biodiesel, B5, quality survey, retail stations.

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INTRODUCTION

Biodiesel, chemically known as fatty acid methyl ester (FAME), has been successfully produced, evaluated and identified as an important alternative fuel (Ali *et al*., 1995; Chang *et al*., 1996; Choo *et al*., 1995; 1997; Clark *et al*., 1984; Cvengros *et al*., 1999; Mittelbach and Enzelsberger, 1999). Biodiesel can be produced from various oils and fats in particular palm oil in the South-east Asia region (Choo *et al*., 1995; 1997). Diesel fuel blended with biodiesel at different allowable percentages have been implemented worldwide either on a voluntary or mandatory basis for the past few years, including Malaysia (Chong, 2013; Gonzalez, 2014; Vora, 2013).

The B5, B10, B20 and B5-B20 biodiesel blends were sold voluntarily at retail stations in Michigan, USA besides the neat diesel and neat ultra-low sulphur diesel (ULSD) (Tang *et al*., 2008). The BX is denoted as blend of X vol.% biodiesel (fatty acid methyl ester) with (100 – X) vol.% petroleum diesel. The biodiesel blends sold were of acceptable quality for parameters such as total acid number, derived cetane number (DCN), kinematic viscosity and cold flow properties. However, 45% of the samples did not meet the minimum 6 hr of the Rancimat induction period (IP). The diesel fuel sold at the same location two years later still demonstrated that almost half of the samples did not comply with the limits for total acid number and oxidation stability as stipulated in the ASTM D 975 and/or D 7467 (Guzman *et al*., 2010). In addition, imprecise levels of the biodiesel blending ratio were detected in both surveys. There were significant variations between the reported and the actual biodiesel blending ratio, reflecting both the inappropriateness and the weakness of the splash blending procedures adopted. In a separate survey carried out nationwide in USA, during winter in 2009/2010, the stability of the B6-B20 biodiesel blends collected from retail stations was found to be problematic with a failure rate of 24% (Alleman *et al*., 2011).

In Malaysia, the B5 (blend of 5 vol.% palm biodiesel with 95 vol.% petroleum diesel) programme was initiated in June 2011 at retail stations in the central region of Peninsular Malaysia, covering the areas of Putrajaya, Negeri Sembilan, Melaka, Kuala

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Lumpur and Selangor. Upon completion of the inline blending facilities at oil terminals at various locations, the B5 programme was further expanded to the southern region (Johor) in July 2013, the eastern region (Pahang, Terengganu and Kelantan) in February 2014 and the northern region (Perak, Pulau Pinang, Kedah and Perlis) in March 2014.

In order to assess the performance of the B5 implementation in Peninsular Malaysia, survey was conducted from January to August 2014 to check on the quality of 80 B5 samples sold at retail stations, and to ensure their compliance with the Malaysian Standard specification for diesel fuel MS123-1:2014 (DSM, 2014). The properties of the B5 samples were compared with those of neat diesel fuels sampled from retail stations in the northern region in October 2013 (before B5 implementation) so as to gauge their performance in diesel car engines.

MATERIALS AND METHODS

Materials

There are five oil companies operating retail businesses in Peninsular Malaysia. For each oil company, 16 diesel samples were obtained from 16 different retail stations at different locations as illustrated in *Figure 1*. The information on specific location, *i.e.* city, state, region and date of sampling are listed in *Table 1*. The names of the oil companies are not provided to remove bias in the analysis, interpretation and presentation of the results. These companies are denoted as OC-1 to OC-5.

Figure 1. Location of the 80 retail stations for sampling of diesel fuel.

Methods

The diesel samples were analysed for their physico-chemical and fuel properties as follows:

Visual appearance inspection. Samples were visually inspected in a 1-litre transparent glass bottle in accordance to ASTM D4176 (ASTM International, 2014c). The presence of water droplets and particulates was recorded, if any.

Colour. The colour of the samples was measured according to ASTM D1500 (ASTM International, 2012d) using a Lovibond Tintotometer model AF 650 POC (Amesbury, UK).

Biodiesel content. The biodiesel content was measured using a Perkin Elmer model Spectrum 400 Fourier transform infrared (FTIR) spectrometer (UK) equipped with an attenuated total reflectance (ATR) sample cell according to ASTM D7371 (ASTM International, 2014e).

Water content. The water content was measured using a Metrohm 831 Karl Fischer Coulometer (Herisau, Switzerland) according to ISO 12937 (ISO, 2000).

Sediment by extraction. Sediment content was determined according to ASTM D473 (ASTM International, 2012c) using a Fisher Scientific extraction apparatus (USA).

Carbon residue on 10% bottoms. Carbon residue content was determined using an Alcor model MCRT-160 (USA) apparatus according to ASTM D189 (ASTM International, 2014a). Each sample was distilled using an automated distillation unit prior to being subjected to the carbon residue test.

Ash content. The samples were burnt to produce ash in a Thermo Concept furnace model KL 15/11 (Germany), and the ash content was calculated according to ASTM D482 (ASTM International, 2013b).

Cold flow properties. The cloud point (CP), pour point (PP) and cold filter plugging point (CFPP) were determined according to the ASTM D5771 (ASTM International, 2012f), D5950 (ASTM International, 2014d) and EN 116 (IP, 1998), respectively. The measurements were performed using an ISL model CPP 97-2 cold flow properties analyser (Verson, France).

Flash point. The flash point was measured according to ASTM D93 (ASTM International, 2013a) using a Pensky-Martens closed cup automated flash point tester (Petrotest, Ludwid-Erhard-Ring, Germany).

TABLE 1. DETAIL LOCATION AND DATE OF SAMPLING OF B5 DIESEL FUELS

Sample ID	Oil company	City	State	Region	Date collected
1	OC-1	Kuala Selangor	Selangor	Central	20-Jan-2014
2	OC-1	Batu Caves	Selangor	Central	20-Jan-2014
3	OC-2	Kuala Selangor	Selangor	Central	20-Jan-2014
4	OC-2	Batu Caves	Selangor	Central	20-Jan-2014
5	OC-3	Kuala Selangor	Selangor	Central	20-Jan-2014
6	OC-3	Batu Caves	Selangor	Central	20-Jan-2014
7	OC-4	Kuala Selangor	Selangor	Central	20-Jan-2014
8	OC-4	Batu Caves	Selangor	Central	20-Jan-2014
9	OC-5	Kuala Selangor	Selangor	Central	20-Jan-2014
10	OC-5	Batu Caves	Selangor	Central	20-Jan-2014
11	OC-1	Banting	Selangor	Central	27-Jan-2014
12	OC-1	Kajang	Selangor	Central	27-Jan-2014
13	OC-2	Banting	Selangor	Central	27-Jan-2014
14	OC-2	Kajang	Selangor	Central	27-Jan-2014
15	OC-3	Banting	Selangor	Central	27-Jan-2014
16	OC-3	Kajang	Selangor	Central	27-Jan-2014
17	OC-4	Banting	Selangor	Central	27-Jan-2014
18	OC-4	Kajang	Selangor	Central	27-Jan-2014
19	OC-5	Banting	Selangor	Central	27-Jan-2014
20	OC-5	Kajang	Selangor	Central	27-Jan-2014
21	OC-1	Puchong	Selangor	Central	11-Feb-2014
22	OC-1	Bukit Jalil	Kuala Lumpur	Central	11-Feb-2014
23	OC-2	Puchong	Selangor	Central	11-Feb-2014
24	OC-2	Bukit Jalil	Kuala Lumpur	Central	11-Feb-2014
25	OC-3	Puchong	Selangor	Central	11-Feb-2014
26	OC-3	Bukit Jalil	Kuala Lumpur	Central	11-Feb-2014
27	OC-4	Puchong	Selangor	Central	11-Feb-2014
28	OC-4	Bukit Jalil	Kuala Lumpur	Central	11-Feb-2014
29	OC-5	Puchong	Selangor	Central	11-Feb-2014
30	OC-5	Bukit Jalil	Kuala Lumpur	Central	11-Feb-2014
31	OC-1	Ampang	Kuala Lumpur	Central	27-Feb-2014
32	OC-1	Bukit Bintang	Kuala Lumpur	Central	27-Feb-2014
33	OC-2	Ampang	Kuala Lumpur	Central	27-Feb-2014
34	OC-2	Bukit Bintang	Kuala Lumpur	Central	27-Feb-2014
35	OC-3	Ampang	Kuala Lumpur	Central	27-Feb-2014
36	OC-3	Bukit Bintang	Kuala Lumpur	Central	27-Feb-2014
37	OC-4	Ampang	Kuala Lumpur	Central	27-Feb-2014
38	OC-4	Bukit Bintang	Kuala Lumpur	Central	27-Feb-2014
39	OC-5	Ampang	Kuala Lumpur	Central	27-Feb-2014
40	OC-5	Bukit Bintang	Kuala Lumpur	Central	27-Feb-2014
41	OC-1	Hutan Melintang	Perak	Northern	23-Apr-2014
42	OC-1	Sitiawan	Perak	Northern	23-Apr-2014
43	OC-2	Hutan Melintang	Perak	Northern	23-Apr-2014
44	OC-2	Sitiawan	Perak	Northern	23-Apr-2014
45	OC-3	Hutan Melintang	Perak	Northern	23-Apr-2014
46	OC-3	Sitiawan	Perak	Northern	23-Apr-2014
47	OC-4	Hutan Melintang	Perak	Northern	23-Apr-2014
48	OC-4	Sitiawan	Perak	Northern	23-Apr-2014
49	OC-5	Hutan Melintang	Perak	Northern	23-Apr-2014
50	OC-5	Sitiawan	Perak	Northern	23-Apr-2014
51	OC-1	Batu Pahat	Johor	Southern	29-Apr-2014
52	OC-1	Kluang	Johor	Southern	29-Apr-2014
53	OC-2	Batu Pahat	Johor	Southern	29-Apr-2014
54	OC-2	Kluang	Johor	Southern	29-Apr-2014
55	OC-3	Batu Pahat	Johor	Southern	29-Apr-2014
56	OC-3	Kluang	Johor	Southern	29-Apr-2014
57	OC-4	Batu Pahat	Johor	Southern	29-Apr-2014
58	OC-4	Kluang	Johor	Southern	29-Apr-2014
59	OC-5	Batu Pahat	Johor	Southern	29-Apr-2014

TABLE 1. DETAIL LOCATION AND DATE OF SAMPLING OF B5 DIESEL FUELS (continued)

Sample ID	Oil company	City	State	Region	Date collected
60	OC-5	Kluang	Johor	Southern	29-Apr-2014
61	OC-1	Pasir Gudang	Johor	Southern	6-Aug-2014
62	OC-1	Johor Bahru	Johor	Southern	6-Aug-2014
63	OC-2	Pasir Gudang	Johor	Southern	6-Aug-2014
64	OC-2	Johor Bahru	Johor	Southern	6-Aug-2014
65	OC-3	Pasir Gudang	Johor	Southern	6-Aug-2014
66	OC-3	Johor Bahru	Johor	Southern	6-Aug-2014
67	OC-4	Pasir Gudang	Johor	Southern	6-Aug-2014
68	OC-4	Johor Bahru	Johor	Southern	6-Aug-2014
69	OC-5	Pasir Gudang	Johor	Southern	6-Aug-2014
70	OC-5	Johor Bahru	Johor	Southern	6-Aug-2014
71	OC-1	Gambang	Pahang	Eastern	16-Aug-2014
72	OC-1	Kuantan	Pahang	Eastern	16-Aug-2014
73	OC-2	Gambang	Pahang	Eastern	16-Aug-2014
74	OC-2	Kuantan	Pahang	Eastern	16-Aug-2014
75	OC-3	Gambang	Pahang	Eastern	16-Aug-2014
76	OC-3	Kuantan	Pahang	Eastern	16-Aug-2014
77	OC-4	Gambang	Pahang	Eastern	16-Aug-2014
78	OC-4	Kuantan	Pahang	Eastern	16-Aug-2014
79	OC-5	Gambang	Pahang	Eastern	16-Aug-2014
80	OC-5	Kuantan	Pahang	Eastern	16-Aug-2014

Electrical conductivity. The electrical conductivity was measured using an Emcee digital conductivity meter model 1152-X1 (Venice, Italy) according to ASTM D2624 (ASTM International, 2009).

Kinematic viscosity at 40°C. The kinematic viscosity was measured at 40°C according to ASTM D445 (ASTM International, 2014b) using a Herzog viscometer model HVM 472 (Lauda-Konigshofen, Germany).

Density at 15°C. The density was measured according to ASTM D4052 (ASTM International, 2011b) using a Mettler-Toledo digital density meter model DE40 (Schwerzenbach, Switzerland) at 15°C.

Physical distillation at 95% recovered volume, T95. The distillation profile was obtained using a PAC model Optidist automated distillation unit (Germany) according to ASTM D86 (ASTM International, 2012a).

Derived cetane number (DCN). The DCN was determined according to ASTM D6890 (ASTM International, 2013c) in an Ignition Quality Tester (IQT™) (Advanced Engine Technology Ltd, Ontario, Canada).

Lubricity. The samples were subjected to a High Frequency Reciprocating Rig (PCS Instruments, London, UK) at 60°C according to ASTM D6079 (ASTM International, 2011c). The lubricity of each sample was characterised by measuring the wear scar diameter (WSD) produced on the upper specimen using a microscope. Short WSD generated indicates better lubricity of the fuel.

Sulphur content. The sulphur content was determined according to ASTM D5453 (ASTM International, 2012e) using a Mitsubishi Total Sulphur Analyser model TS-100 (Kanagawa, Japan).

Oxidation stability. The oxidation stability was determined via the IP. The IP was measured according to ASTM D7545 (ASTM International, 2013d) using PetroOXY (Petrotest, Ludwid-Erhard-Ring, Germany) at 140°C in an oxygen pressurised vessel.

Copper strip corrosion. Copper strip corrosion was performed for 3 hr at 50°C according to ASTM D130 (ASTM International, 2012b), using a Petrotest DP bath (Ludwid-Erhard-Ring, Germany). The corrosion readings were reported based on a comparison of the copper strips against the standard.

Acid number. The acid number of the sample was determined according to ASTM D664 (ASTM International, 2011a) using a Metrohm 809 Titrando (Herisau, Switzerland).

RESULTS AND DISCUSSION

The physico-chemical and fuel properties of the B5 diesel fuels obtained from five oil companies are summarised in *Table 2*. *Table 3* presents the properties of the neat diesel fuels obtained from the northern

TABLE 2. SUMMARY OF PHYSICO-CHEMICAL AND FUEL PROPERTIES OF B5 DIESEL FUELS

Properties	Test method	Unit	MS123-1:2014	OC-1	OC-2	OC-3	OC-4	OC-5
1. Colour (ASTM)	ASTM D1500	-	2.5 max	L0.5 to L1.0	L0.5 toL1.0	L0.5 toL2.5	L0.5	L0.5 to L1.0
2. FAME content	ASTM D7371	vol. %	7.0 max	4.65 to 5.16	4.61 to 5.23	4.99 to 5.31	4.92 to 5.33	4.86 to 5.26
3. Water	ISO 12937	mg kg^{-1}	500 max	75 to 182	82 to 125	81 to 124	63 to 131	67 to 182
4. Sediment by extraction	ASTM D473	mass %	0.01 max	0 to 0.01	0 to 0.01	0 to 0.01	0 to 0.01	0 to 0.01
5. Ash	ASTM D482	mass %	0.01 max	<0.001 to 0.001	<0.001 to 0.001	<0.001 to 0.001	<0.001 to 0.001	<0.001
6. Conradson carbon residue on 10% distillation residue	ASTM D189	mass %	0.2 max	<0.1	<0.1	<0.1	<0.1	<0.1
7. Cloud point	ASTM D5771	°C	19 max	-2.6 to 4.7	0.6 to 8.6	4.5 to 13.9	3.8 to 8.2	0.8 to 8.1
8. Pour point	ASTM D5950	°C	-	-9 to -3	-9 to 3	-6 to 9	-3 to 3	-9 to 3
9. Cold filter plugging point	EN 116	°C	-	-12 to -4	-11 to 6	-4 to 12	-4 to 6	-13 to 7
10. Flash point	ASTM D93	°C	60 min	65.5 to 75.5	68.5 to 80.5	63.5 to 71.5	66.5 to 80.5	67.5 to 75.5
11. Electrical conductivity	ASTM D2624	pS m^{-1}	50 min	268 to 700	87 to 498	278 to 840	287 to 754	369 to 1283
12. Kinematic viscosity at 40°C	ASTM D445	mm^2 s^{-1}	1.5 to 5.8	2.75 to 3.52	3.28 to 3.96	2.90 to 3.73	3.24 to 3.93	3.22 to 3.83
13. Density at 15°C	ASTM D4052	g ml^{-1}	0.81 to 0.87	0.83 to 0.86	0.81 to 0.86	0.83 to 0.85	0.83 to 0.86	0.84 to 0.86
14. Acid number	ASTM D664	mg KOH g^{-1}	0.25 max	0.01 to 0.08	0.01 to 0.08	0.01 to 0.11	0.03 to 0.07	0.01 to 0.06
15. Copper strip corrosion (3 hr at 100°C)	ASTM D130	rating	1 max	1a	1a	1a	1a	1a
16. Physical distillation at 95% recovered volume	ASTM D86	°C	370 max	348 to 365	356 to 366	363 to 369[a]	358 to 366	357 to 366
17. Derived cetane number	ASTM D6890	-	49 min	49.1 to 54.2[b]	50.5 to 54.9	52.1 to 62.2	50.6 to 56.9	51.3 to 60.1[c]
18. Lubricity	ASTM D6079	μm	460 max	174 to 213	174 to 280	172 to 239	174 to 363	173 to 220
19. Total sulphur	ASTM D5453	mg kg^{-1}	500 max	207 to 456	275 to 431	271 to 456	274 to 398	277 to 429
20. Oxidation stability (PetroOXY)	ASTM D7545	min	65 min[d]	137 to 1225	71 to 780[e]	73 to 1067	216 to 1199	109 to 590

Note: [a] One sample slightly exceeded 370°C max limit (371°C).
[b] Three samples lower than the 49 min limit (47 to 48).
[c] One sample lower than the 49 min limit (48).
[d] Recommended by car manufacturers (ACEA *et al.*, 2013).
[e] One sample lower than 65 min limit (46 min).

TABLE 3. PHYSICO-CHEMICAL AND FUEL PROPERTIES OF NEAT DIESEL FUELS

Properties	Test method	Unit	MS123-1:2014	OC-1	OC-2	OC-3	OC-4	OC-5
1. Colour (ASTM)	ASTM D1500	-	2.5 max	L0.5	L0.5	L0.5	L0.5	L0.5
2. Water by distillation	ASTM D95	vol %	0.05 max	<0.05	<0.05	<0.05	<0.05	<0.05
3. Water	ISO 12937	mg kg^{-1}	500 max	84	72	64	72	88
4. Sediment by extraction	ASTM D473	mass %	0.01 max	0.01	0.01	0.01	0.01	0.01
5. Ash	ASTM D482	mass %	0.01 max	<0.001	<0.001	<0.001	<0.001	<0.001
6. Conradson carbon residue on 10% distillation residue	ASTM D189	mass %	0.2 max	<0.1	<0.1	<0.1	<0.1	<0.1
7. Cloud point	ASTM D5771	°C	19 max	1.1	4.3	10.9	4.7	7.3
8. Pour point	ASTM D5950	°C	-	-3	0	9	3	6
9. Cold filter plugging point	EN 116	°C	-	-2	2	11	3	6
10. Flash point	ASTM D93	°C	60 min	80.0	75.0	64.0	72.0	65.0
11. Electrical conductivity	ASTM D2624	pS m^{-1}	50 min	197	87	328	512	685
12. Kinematic viscosity at 40°C,	ASTM D445	mm^2 s^{-1}	1.5 to 5.8	3.5041	4.0224	2.8818	3.6353	3.1868
13. Density at 15°C	ASTM D4052	g ml^{-1}	0.81 to 0.87	0.8441	0.8449	0.8333	0.8451	0.8554
14. Acid number	ASTM D664	mg KOH g^{-1}	0.25 max	0.02	0.02	0.09	0.04	0.02
15. Copper strip corrosion (3 hr at 100°C)	ASTM D130	rating	1 max	1a	1a	1a	1a	1a
16. Physical distillation at 95% recovered volume	ASTM D86	°C	370 max	359	368	365	362	369
17. Derived cetane number	ASTM D6890	-	49 min	51.5	51.8	58.3	52.0	52.3
18. Lubricity	ASTM D6079	μm	460 max	411.5	362.0	347.5	357.5	369.5
19. Total sulphur	ASTM D5453	mg kg^{-1}	500 max	426	409	338	408	288
20. Oxidation stability (PetroOXY)	ASTM D7545	min	65 min[a]	495	121	1051	530	864

Note: [a] Recommended by car manufacturers (ACEA *et al.*, 2013).

region of Peninsular Malaysia in October 2013, prior to the implementation of the B5 programme. These data served as the basis for comparison with the properties of the B5 diesel samples. The samples in the current study were tested only once to assess their compliance with the Malaysian Standard Specification for Diesel Fuel, MS123-1:2014. Reproducibility (R) of the results of the test methods were indicated in the captions for figures.

All 80 B5 diesel samples passed the visual inspection. The samples were found clear and bright without the presence of water and/or particulates, thus indicating no possible contamination in the B5 diesel fuel. The colour of the B5 diesel sample was in the range of L0.5 to L1.5, except for one sample, which was slightly darker, and the result of L2.5 was reported. Overall, the appearance of all of the samples was acceptable and there were no signs of unusual contamination and fuel degradation.

Biodiesel was blended into diesel fuel via inline blending facilities installed at various oil terminals prior to distribution to the respective retail stations. The measured biodiesel content in B5 diesel fuels was in the range of 4.61 vol.% to 5.33 vol.%. This indicated that the inline blending facilities were able to provide homogenous blending in accordance with the mandate set by the government, *i.e.* 5 vol. % biodiesel.

The water content of the B5 diesel fuels is shown in *Figure 2*. All the 80 B5 diesel samples were found to have water content well below 200 mg kg^{-1}, meeting the stringent requirement of 0.05 vol.% as stipulated in MS123-1:2014 (DSM, 2014) and the 200 mg kg^{-1} maximum limit requested by car manufacturers (ACEA *et al*., 2013). The sediment in all the 80 B5 diesel samples showed consistent readings which ranged from 0 to 0.01 mass%; the lowest detectable limit as stipulated in ASTM D473. To provide more sensitive readings at parts per million levels, methods such as total contamination EN 12662 should be considered in the future study.

All the B5 diesel samples were in full compliance with the carbon residue and ash specifications, *i.e.* <0.1 mass% and ≤0.001 mass%, respectively. This indicated that all the B5 diesel fuels were free of any carbonaceous residues and thus indicating no formation of non-burnable deposits which may contribute to wear and tear in the fuel system, *i.e*. fuel injector, fuel pump and piston (ACEA *et al.*, 2013; Westbrook and LeCren, 2009).

The CP, PP and CFPP are parameters determining the operational behaviour of a diesel fuel at the lowest possible temperature. In MS123-1:2014, only CP was selected as a specification for the cold flow behaviour of diesel fuel. All of the B5 diesel samples complied with the CP requirement specified in MS123-1:2014, with 10 samples having CP values of 10°C to 15°C, 37 samples in the range of 5°C to 10°C, and the remaining 33 samples <5°C. The highest CP recorded *i.e.* 13.9°C was well below the upper limit set (19°C), enabling B5 diesel fuel to be used all year round in hot climate like Malaysia. *Figures 3* to *5* show the differences in the cold flow properties, *i.e*. CP, PP and CFPP for the diesel fuels supplied by all five oil companies. All of them exhibited similar cold flow behaviours; with fuel from OC-3 having a higher cold flow temperature while fuels from OC-2, OC-4 and OC-5 at a moderate range, and OC-1 at a lower range. Additionally, blending of 5 vol. % palm biodiesel into petroleum diesel hardly showed any changes on its cold flow properties. This was evidenced from the insignificant increment of the CP, PP and CFPP of the B5 diesel samples, despite palm biodiesel possessing much higher cold flow properties, *i.e* 15°C (Yung *et al*., 2006; 2013).

The flash points of all the B5 diesel fuels were in the range of 63.5°C to 80.5°C, thus complying

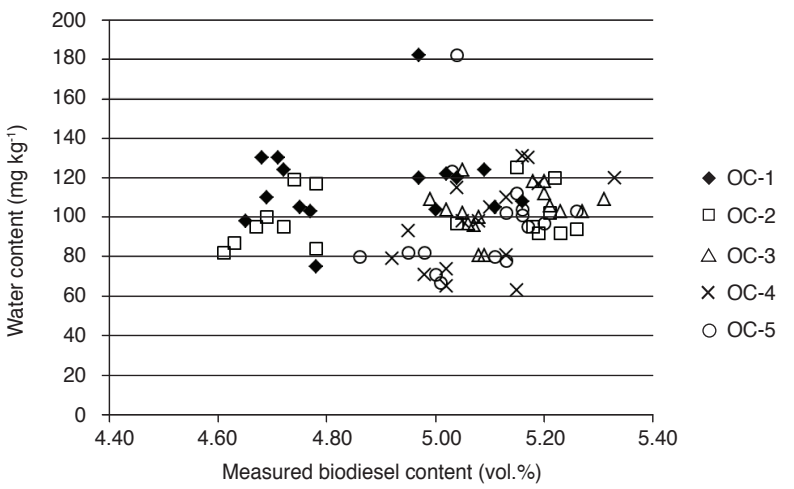

Figure 2. Plot of the water content vs. *the measured biodiesel content of the diesel samples obtained from five oil companies. R = 0.0477(X + 14.905) for biodiesel [fatty acid methyl ester (FAME)] content, R = 0.06877X^0.5 for water content.*

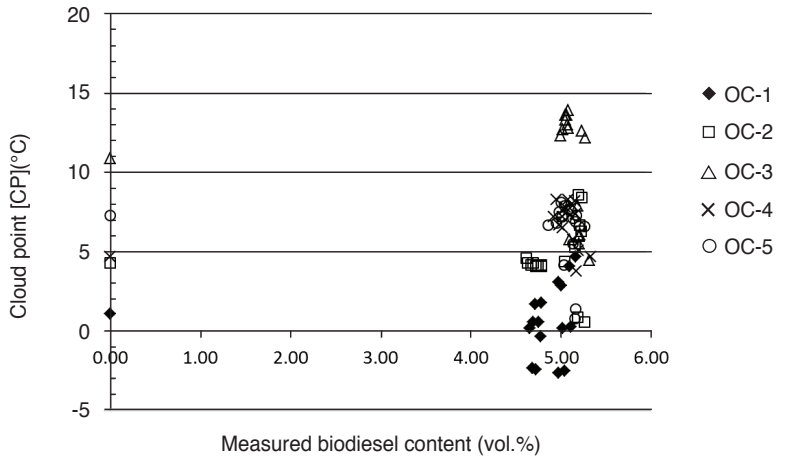

Figure 3. Cloud points vs. *measured biodiesel content of diesel samples obtained from five oil companies. R = 0.0477(X + 14.905) for biodiesel [fatty acid methyl ester (FAME)] content, R = 2.7°C for cloud point.*

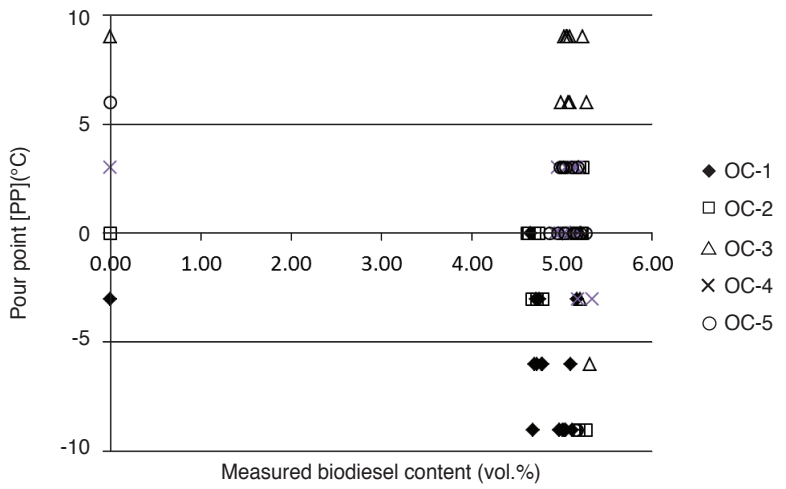

Figure 4. Plot of the pour point vs. *the measured biodiesel content of the diesel samples obtained from five oil companies. R = 0.0477(X + 14.905) for biodiesel [fatty acid methyl ester (FAME)] content, R = 6.1°C for pour point.*

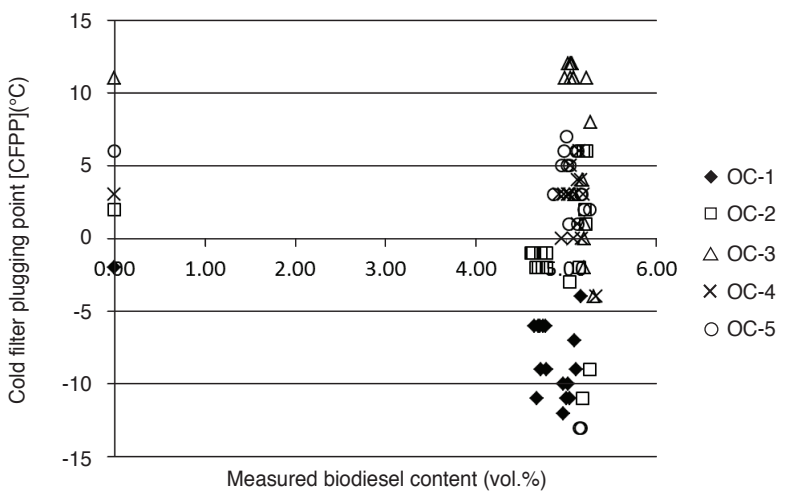

Figure 5. Plot of the CFPP vs. *the measured biodiesel content of the diesel samples obtained from five oil companies. R = 0.0477(X + 14.905) for biodiesel [fatty acid methyl ester (FAME)] content, R = 0.103(25-X) for cold filter plugging point.*

with the minimum requirement set for local diesel consumption, *i.e.* 60°C. Similar to the cold flow properties, the blending of 5 vol.% of biodiesel into petroleum diesel showed insignificant effect, despite palm biodiesel exhibiting much higher flash point, *i.e.* 182°C (Yung *et al*., 2006; 2013). Nevertheless, this also indicated that the B5 diesel fuel is safe to be stored and transported throughout Malaysia for B5 implementation. This was further supported by the high conductivity of the B5 diesel fuels indicating rapid charges dissipation during pumping and filtration operations, thereby preventing the accumulation of charges and avoiding potential dangerous explosion in the storage tank.

The kinematic viscosity and density of all the B5 diesel samples were within the specified limits, *i.e.* in the ranges of 2.75 to 3.96 $mm^2 s^{-1}$ and 0.81 to 0.86 $g ml^{-1}$, respectively. The copper strip corrosion and the acid number serve as parameters that indirectly indicate the degradation of a fuel. All the B5 samples demonstrated class 1a for the copper strip corrosion and acid number in the range of 0.01 to 0.11 mg KOH g^{-1}. As such, there was no degradation in the B5 diesel; all of them were well preserved during storage and transportation and thus, the was no formation of oxidised acidic compounds that could harm the engine components.

For distillation, only one out of 80 samples slightly exceeded the temperature limit at the 95% recovered volume (T95) *i.e.* 370°C *vs*. 371°C; thus may have slight tendency to generate more tailpipe emission from the vehicles in use. In particular, higher NOx and particulate matter emission from heavy and light duty engines, respectively could be anticipated (ACEA *et al*., 2013).

In general, all the neat diesel and B5 diesel fuels met the minimum DCN limit of 49 except for four samples with slightly lower DCN value of 47 to 48. The B5 diesel fuels in the present study had a slightly improved DCN compared to those of neat diesel fuels. The DCN of neat diesel and B5 diesel fuels from OC-3 was the highest, probably due to the higher concentration of straight chain paraffinic hydrocarbons in the diesel component which had the tendency to ignite more readily under compression compared to those of branched chain and aromatic hydrocarbons in the rest of the blended fuels (Westbrook and LeCren, 2009). However, the presence of higher straight chain paraffinic hydrocarbons also had a higher tendency to crystallise at higher temperature thus affecting the cold flow behaviours of a fuel such as the one observed from OC-3 (*Figures 6* and *7*).

The lubricity of a fuel is characterised by measuring the WSD produced on the steel ball reciprocated on a steel disk under specific pressure and temperature in the presence of a thin layer of fuel. A shorter WSD represents a higher lubricity property. *Figure 8* shows that the WSD of the B5 diesel samples were much shorter, thus better lubricity than those for the neat diesel samples. Generally, blending 5 vol.% of palm biodiesel into the neat diesel had significantly enhanced its lubricity from a maximum WSD of 460 μm to <300 μm.

Palm biodiesel is typically low in sulphur content (Yung *et al*., 2013). Theoretically, blending 5 vol.% of palm biodiesel into neat diesel will relatively lower its sulphur content by approximately 5%. The sulphur content of the B5 diesel samples in the present study ranged from 210 to 456 mg kg^{-1}, thus complying with the limit (500 mg kg^{-1}) allowable in Malaysia. In fact, Malaysia has planned to further reduce the sulphur content to 10 mg kg^{-1} in the near future. This can be done via hydrotreating process in petroleum refineries; with the shortcoming that this will result in poorer lubricity of the fuel produced. However, this negative attribute can be overcome by the national biodiesel programme. The presence of palm biodiesel, even at a small quantity, *i.e.* 5 vol.%, is able to restore the lubricity of the fuel; thus the addition of an expensive lubricity additive is not required.

Oxidation stability is a concern when biodiesel is introduced into a diesel fuel. Biodiesel is more susceptible to oxidation, especially in the presence of water and air. However, palm biodiesel is also known to have a superior oxidation stability among all of the biodiesels produced from oils and fats (Yung *et al*., 2006; 2013). The present study employed PetroOXY (ASTM D7545) as a means to suitably accelerate oxidation of the B5 diesel fuels. As indicated in *Tables 2* and *3*, of all the 80 B5 diesel samples, only one sample did not pass the OEM recommended minimum IP of 65 min, the rest with IP >65 to 1206 min (*Figure 9*). The less stable B5 samples (IP between 65-100 min) and their neat counterparts were mainly from OC-2 at central region. Since there was no sign of any increase in the acid number and water content, and all passed the copper strip corrosion test, the less stability of the B5 samples was probably inherited from the neat diesel component; thus eliminating the possible cause by long-term storage and/or fuel degradation in the underground fuel tanks.

CONCLUSION

The B5 diesel fuels obtained from 80 retail stations contained 4.61 vol.% to 5.33 vol.% palm biodiesel with very promising quality. This showed great commitment by the oil companies to support the national B5 programme. All the samples were in full compliance with the parameters stipulated in the local diesel specification, except for one slightly exceeded the T95 temperature and oxidation IP, and few others with slightly lower DCN than the locally allowed standards. More importantly, all the

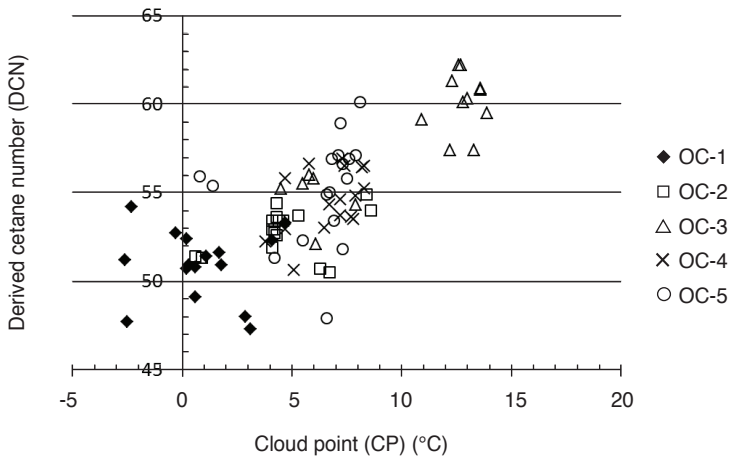

Figure 6. Plot of the derived cetane number vs. *the cloud point of the diesel samples obtained from five oil companies. R = 0.0385(X + 18) for DCN, R = 2.7 °C for cloud point.*

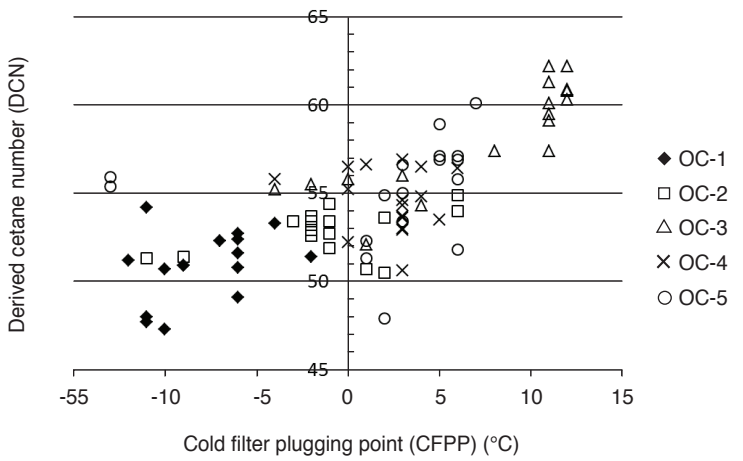

Figure 7. Plot of the derived cetane number vs. *the cold filter plugging point (CFPP) of the diesel samples obtained from five oil companies. R = 0.0385(X + 18) for DCN, R = 0.103(25 - X) for CFPP.*

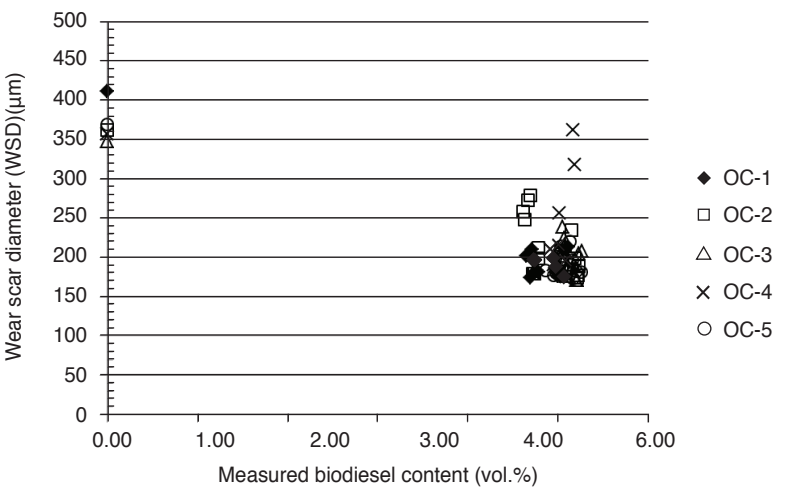

Figure 8. Plot of the wear scar diameter (WSD) value vs. *the measured biodiesel content of the diesel samples obtained from five oil companies. R = 0.0477(X + 14.905) for biodiesel [fatty acid methyl ester (FAME)] content, R = 80 µm for lubricity.*

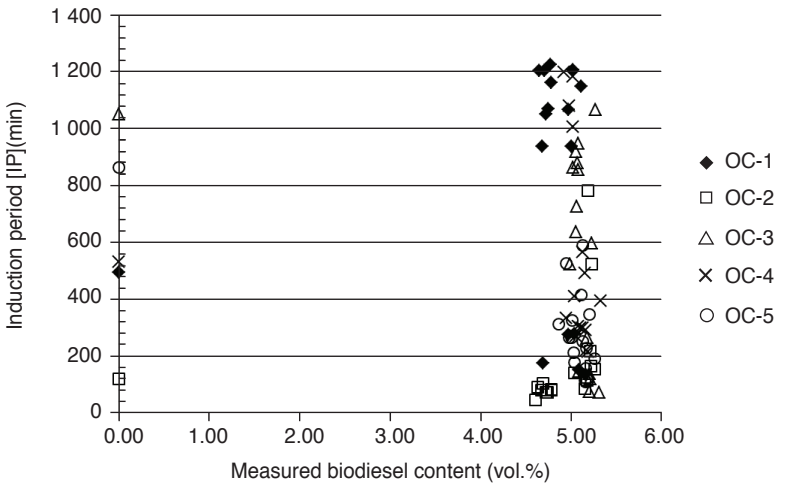

Figure 9. Plot of the induction period (IP) values vs. *the measured biodiesel content of the diesel samples obtained from five oil companies. R = 0.0477(X + 14.905) for biodiesel [fatty acid methyl ester (FAME)] content, R = 0.0863X + 1.3772 for oxidation stability.*

samples complied with the stringent requirement of a low water content (<200 mg kg^{-1}) and demonstrated superior oxidative stability. In general, the 5 vol.% palm biodiesel blended had not just maintained the fuel quality but improved significantly some of the fuel properties, *e.g*. the ignition quality and lubricity.

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