Feature Article

Physicochemical Properties of B10 Diesel

Chee Liang Yung* and Soh Kheang Loh*

INTRODUCTION

The concept of using vegetable oils as fuel dated back to 1895 when the first diesel engine powered by peanut oil was developed by Dr Rudolf Diesel (Sheaves, 2001). However, the use of vegetable oil as fuel became insignificant when crude oil was discovered a few years later. Biofuel from vegetable oils once again drew world's attention due to the energy crisis in the 1970s. With increasing concern on environment, rising oil price and rapid technological advancement, biofuel in the form of biodiesel has emerged as an important alternative fuel at present.

Biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from renewable lipid sources such as vegetable oils and animal fats (ASTM International, 2015). Biodiesel is a petroleum diesel substitute, and it can be used in compression ignition engines with little or no modification. It has physical properties similar to petroleum diesel (Knothe and Dunn, 2001; Mittelbach and Remschmidt, 2004). Biodiesel is widely used as a blending stock for petroleum diesel.

MPOB has embarked on research and development of palm biodiesel or palm methyl ester (PME) way back in 1982 (Choo *et al.*, 1997). The first pilot plant for the production of PME was constructed in 1985. Subsequently, exhaustive field trials were carried out in collaboration with various parties, in particular, the Mercedes Benz-AG, Germany. The trials have concluded that PME is a suitable substitute for petroleum diesel (Choo *et al.*, 1997). However, due to economic reason, PME was only commercially viable and available in Malaysia in 2006. To date, 16 biodiesel plants are in operation in Malaysia with a total production capacity of 2.06 million tonnes per annum (Kushairi, 2018). B5 diesel (blends of 5% PME with 95% petroleum diesel based on volume percentage) was introduced to the petrol stations to partially replace conventional diesel in June 2011 (Yung *et al.*, 2016). B7 diesel has subsequently replaced B5 diesel in November 2014 (Nursyairah *et al.*, 2017). At the moment, all diesel fuels supplied in petrol stations in the country are of 7 vol.% PME blend (B7).

The government has a plan to increase the PME ratio to 10 vol.% in petroleum diesel. Hence, studies on B10 diesel in particularly the physicochemical properties is crucial for the development of the B10 diesel standard. This paper presents the properties of B10

* *Malaysian Palm Oil Board*
6, Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.
E-mail: clyung@mpob.gov.my

diesel and also provides readers with a better understanding of its properties compared to neat petroleum diesel.

ANALYSIS OF PALM BIODIESEL BLENDS

Five neat petroleum diesel samples were obtained from five different oil companies operating a retail business in Malaysia. Eight PME samples were obtained from PME producers in the country. The petroleum diesel samples were labelled as Diesel A to Diesel E while the PME samples were labelled as PME 1 to PME 8.

B10 diesel samples were prepared by blending 10 vol.% of PME 1 to PME 8 with 90 vol.% of Diesel A to Diesel E. The B10 diesel samples were labelled accordingly, *e.g.* Diesel A with PME 1 as A1, Diesel A with PME 2 as A2, Diesel A with PME 3 as A3, *etc*. The petroleum diesel and B10 diesel samples were subjected to physicochemical property analyses according to the parameters stipulated in the Malaysian standard specification for diesel fuel, MS123-1:2014 (Department of Standards Malaysia, 2014). *Table 1* lists the test methods for the analyses of each parameter and their limits. The obtained properties of B10 diesel samples were compared with the respective neat diesel.

PROPERTIES OF NEAT PETROLEUM DIESEL

There are two grades of petroleum diesel supplied to the Malaysian market, the Euro 2M diesel and Euro 5 diesel. Euro 2M diesel is the mandatory diesel supplied in every petrol station while Euro 5 diesel is supplied voluntarily by oil companies in selected petrol stations. The main difference between them is the maximum limit of sulphur content: 500 mg kg^{-1} and 10 mg kg^{-1} for Euro 2M diesel and Euro 5 diesel, respectively. As the sulphur content differs significantly, Euro 5 diesel is considered much cleaner than Euro 2M diesel with regards to exhaust emissions of the vehicles. As mentioned earlier, currently both the Euro

TABLE 1. TEST METHODS AND LIMITS FOR PETROLEUM DIESEL AS STIPULATED IN MS 123-1:2014

	Property	Method	Unit	Limit
1.	Colour (ASTM)	ASTM D1500	-	2.5 max
2.	Ash	ASTM D482	mass %	0.01 max
3.	Cloud point	ASTM D2500	°C	19.0 max
4.	Flash point	ASTM D93	°C	60 min
5.	Kinematic viscosity at 40°C	ASTM D445	$mm^2 s^{-1}$	1.5-5.8
6.	Copper corrosion (3 h at 100°C)	ASTM D130	Rating	1 max
7.	Water by distillation	ASTM D95	vol.%	0.05 max
8.	Water content	ISO 12937	mg kg^{-1}	-
9.	Sediment by extraction	ASTM D473	mass %	0.01 max
10.	Carbon residue on 10% bottoms	ASTM D189	mass %	0.2 max
11.	Density at 15°C	ASTM D4052	kg L^{-1}	0.81-0.87
12.	Acid number	ASTM D664	mg KOH g^{-1}	0.25 max
13.	Electrical conductivity	ASTM D2624	pS m^{-1}	50 min
14.	Physical distillation at 95% recovered volume	ASTM D86	°C	370 max
15.	Cetane number	ASTM D6890	-	49 min
16.	Lubricity	ASTM D6079	μm	460 max
17.	Total sulphur	ASTM D5453	mg kg^{-1}	500 max

2M diesel and Euro 5 diesel supplied in petrol stations nationwide consist of 7 vol.% of PME (Nursyairah *et al.*, 2017).

As Euro 5 diesel is not commonly used, our evaluation focused on the effect of 10 vol.% of PME to the quality of Euro 2M diesel. The sulphur content of Diesel A to Diesel E samples ranged 288 mg kg^{-1}-426 mg kg^{-1} (*Table 2-Table 6*), meeting the Malaysian standard MS 123-1:2014 as well as the Regulation 4(1)(b) of the Environmental Quality (Control of Petrol and Diesel Properties) Regulations 2007 (*Table 7*).

Some distinct differences were observed for Diesel C compared with other diesel samples. Diesel C possessed a much higher cloud point of 16°C than the other four diesel fuels (<10°C) but still within the limit set at 19°C maximum in MS 123:1:2014. Diesel with high cloud point is known to be unsuitable for cold climate conditions. However, this is not an issue for hot climate countries like Malaysia. The presence of more straight chain paraffinic hydrocarbons which further led to a higher derived cetane number (DCN) was anticipated as the cause of high cloud point in Diesel C (*Table 4*). In summary, all the five petroleum diesel samples available commercially are in full compliance with the MS 123-1:2014.

PROPERTIES OF B10 DIESEL

All the petroleum diesel samples were blended separately with 10 vol.% PME 1 to PME 8. Their properties are presented in *Table 2*. In general, all the B10 diesel samples complied with the requirements stipulated in the MS123-1:2014. No significant changes

TABLE 2. PROPERTIES OF B10 DIESEL A

	Property	Test method	Unit	Diesel A	A1	A2	A3	A4	A5	A6	A7	A8
1.	Colour (ASTM)	ASTM D1500	-	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5
2.	Ash	ASTM D482	mass %	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
3.	Cloud point	ASTM D2500	°C	1	4	5	4	3	2	1	5	6
4.	Flash point	ASTM D93	°C	80.0	81.0	82.0	81.0	82.0	81.0	82.0	73.0	83.0
5.	Kinematic viscosity at 40°C	ASTM D445	$mm^2 s^{-1}$	3.519	3.585	3.587	3.578	3.584	3.580	3.581	3.591	3.634
6.	Copper corrosion (3 h at 100°C)	ASTM D130	Rating	1a	1a	1b	1a	1a	1a	1a	1b	1a
7.	Water by distillation	ASTM D95	vol. %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
8.	Water content	ISO 12937	mg kg^{-1}	84	107	108	87	106	102	118	121	95
9.	Sediment by extraction	ASTM D473	mass %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
10.	Carbon residue on 10% bottoms	ASTM D189	mass %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11.	Density at 15°C	ASTM D4052	kg L^{-1}	0.8441	0.8469	0.8470	0.8470	0.8470	0.8470	0.8470	0.8464	0.8470
12.	Acid number	ASTM D664	mg KOH g^{-1}	0.02	0.03	0.02	0.04	0.03	0.04	0.04	0.03	0.04
13.	Electrical conductivity	ASTM D2624	pS m^{-1}	197	200	244	230	267	253	207	253	251
14.	Physical distillation at 95% recovered volume	ASTM D86	°C	359	360	360	360	360	356	360	359	357
15.	Cetane number	ASTM D6890	-	51.5	53.1	55.6	54.4	54.5	54.1	53.5	54.3	53.3
16.	Lubricity	ASTM D6079	µm	411.5	156.0	162.0	292.0	176.0	317.5	188.5	200.5	170.5
17.	Total sulphur	ASTM D5453	mg kg^{-1}	426	391	387	388	388	387	387	371	390

TABLE 3. PROPERTIES OF B10 DIESEL B

	Properties	Test method	Unit	Diesel B	B1	B2	B3	B4	B5	B6	B7	B8
1.	Colour (ASTM)	ASTM D1500	-	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5	L1.0	L1.0	L1.0
2.	Ash	ASTM D482	mass %	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001
3.	Cloud point	ASTM D2500	°C	6	9	5	6	9	6	6	6	7
4.	Flash point	ASTM D93	°C	75.0	76.0	76.0	76.0	76.0	75.0	77.0	67.0	78.0
5.	Kinematic viscosity at 40°C	ASTM D445	$mm^2 s^{-1}$	4.027	4.048	4.049	4.035	4.042	4.031	4.034	4.062	4.114
6.	Copper corrosion (3 hr at 100°C)	ASTM D130	Rating	1a	1a	1a	1a	1a	1a	1a	1a	1a
7.	Water by distillation	ASTM D95	vol. %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
8.	Water content	ISO 12937	$mg kg^{-1}$	72	112	122	88	105	97	82	148	115
9.	Sediment by extraction	ASTM D473	mass %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
10.	Carbon residue on 10% bottoms	ASTM D189	mass %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11.	Density at 15°C	ASTM D4052	$kg L^{-1}$	0.8449	0.8523	0.8521	0.8522	0.8523	0.8522	0.8522	0.8519	0.8525
12.	Acid number	ASTM D664	mg KOH g^{-1}	<0.02	0.03	0.02	0.04	0.03	0.03	0.03	0.04	0.04
13.	Electrical conductivity	ASTM D2624	$pS m^{-1}$	87	98	126	108	126	92	82	69	72
14.	Physical distillation at 9 % recovered volume	ASTM D86	°C	368	364	365	364	353	365	365	365	364
15.	Cetane number	ASTM D6890	-	51.8	53.9	56.3	53.0	56.2	54.4	53.8	59.2	59.3
16.	Lubricity	ASTM D6079	µm	362	166.5	121.5	297	182.5	285.5	172.5	176.0	164.0
17.	Total sulphur	ASTM D5453	$mg kg^{-1}$	409	372	374	373	367	375	377	362	369

were observed in their properties except for slight increases though insignificant in cloud point, kinematic viscosity, water content, density and acid number. On top of that, approximately 10% reduction in sulphur content was observed in all B10 samples, mainly attributed to the low sulphur content exhibited by PME itself, *i.e.* <10 mg kg^{-1} (Yung *et al.*, 2013)

Cetane number is a prime indicator in assessing the quality of diesel fuel. Its minimum is 49 to meet the MS123-1:2014 requirement and the Regulation 4(1)(b) of the Environmental Quality (Control of Petrol and Diesel Properties) Regulations 2007. As palm biodiesel is a cetane improver (Yung *et al.*, 2016), its presence in B10 samples shows great improvement in DCN from 0.2% to 6% higher than petroleum diesel (Diesel A to Diesel E).

Diesel engines rely on the lubrication property of the fuel to lubricate some of the important engine parts such as fuel pumps and fuel injectors (Knothe, 2010). The lubricity characteristics of a diesel fuel are crucial to safeguard the durability and smooth operation of the engine components. This lubricity property can be assessed based on the wear scar diameter (WSD) generated on a steel ball using a high-frequency reciprocating rig. A small WSD indicates better lubricity of a diesel fuel. In this study, the WSD recorded for B10 diesel samples was significantly smaller; with 12% to 66% reduction compared to petroleum diesel.

TABLE 4. PROPERTIES OF B10 DIESEL C

	Property	Test method	Unit	Diesel C	C1	C2	C3	C4	C5	C6	C7	C8
1.	Colour (ASTM)	ASTM D1500	-	L0.5	0.5	L0.5	L0.5	L0.5	L0.5	1.0	L1.0	L1.0
2.	Ash	ASTM D482	mass %	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
3.	Cloud point	ASTM D2500	°C	16	14	13	12	14	14	14	15	15
4.	Flash point	ASTM D93	°C	64.0	65.0	65.0	65.0	65.0	65.0	65.0	59.0	67.0
5.	Kinematic viscosity at 40°C	ASTM D445	$mm^2 s^{-1}$	2.888	3.004	3.005	2.996	3.004	2.999	2.999	3.023	3.055
6.	Copper corrosion (3 hr at 100°C)	ASTM D130	Rating	1a	1b	1a	1a	1a	1a	1a	1a	1a
7.	Water by distillation	ASTM D95	vol. %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
8.	Water content	ISO 12937	$mg kg^{-1}$	64	92	114	92	96	103	91	122	91
9.	Sediment by extraction	ASTM D473	mass %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
10.	Carbon residue on 10% bottoms	ASTM D189	mass %	<0.1	0.10	<0.1	0.10	<0.1	<0.1	<0.1	<0.1	<0.1
11.	Density at 15°C	ASTM D4052	$kg L^{-1}$	0.8333	0.8372	0.8371	0.8372	0.8373	0.8373	0.8372	0.8368	0.8373
12.	Acid number	ASTM D664	mg KOH g^{-1}	0.09	0.10	0.08	0.11	0.10	0.10	0.10	0.10	0.11
13.	Electrical conductivity	ASTM D2624	$pS m^{-1}$	328	291	399	372	432	417	299	547	437
14.	Physical distillation at 95% recovered volume	ASTM D86	°C	365	365	364	364	363	365	364	364	365
15.	Cetane number	ASTM D6890	-	58.3	58.5	58.7	58.4	58.9	59.0	58.6	60.6	59.7
16.	Lubricity	ASTM D6079	µm	347.5	194.5	182.5	300.0	177.5	304.5	190.0	206.5	186.5
17.	Total sulphur	ASTM D5453	$mg kg^{-1}$	338	308	311	304	306	321	315	306	305

CONCLUSION

Based on the properties evaluated, all the B10 diesel samples are within the parameter limits stipulated in the MS 123-1:2014. As such, B10 diesel can be suitably used as diesel fuel to improve the performance of diesel engines with added advantages of better DCN and lubricity characteristics.

ACKNOWLEDGEMENT

The authors wish to thank the Director-General of MPOB for permission to publish this paper. Sincere thanks are also attributed to the oil companies and PME producers for supplying the samples for the study.

REFERENCES

ASTM International (2015). ASTM D6751-15C^{E1} Standard specification for biodiesel fuel blend stock (B100) for middle distillate fuels. ASTM International, West Conshohocken.

Choo, Y M; Ma, A N and Ong, A S H (1997). Biofuels. In: Gunstone, F D and Padley, F B; editors. *Lipids: Industrial Applications and Technology*, New York: Marcell Dekker Inc, 771-785.

Department of Standards Malaysia (2014). MS123-1: 2014 Malaysian Standard - Diesel – Specification - Part 1: Euro 2M (fourth revision). Department of Standards Malaysia, Ministry of Science, Technology and Innovation, Cyberjaya.

ILBS (2014). Environmental quality (control of petrol and diesel properties) regulations 2007. *Environmental Quality Act 1974 (Act 127), Regulations, Rules and Orders*, Selangor: ILBS, 341-352.

TABLE 5. PROPERTIES OF B10 DIESEL D

	Properties	Test method	Unit	Diesel D	D1	D2	D3	D4	D5	D6	D7	D8
1.	Colour (ASTM)	ASTM D1500	-	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5	L1.0	-	-
2.	Ash	ASTM D482	mass %	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-
3.	Cloud point	ASTM D2500	°C	8	9	10	4	7	5	5	-	-
4.	Flash point	ASTM D93	°C	72.0	75.0	74.0	74.0	76.0	76.0	75.0	-	-
5.	Kinematic viscosity at 40°C	ASTM D445	$mm^2 s^{-1}$	3.644	3.692	3.696	3.684	3.692	3.689	3.689	-	-
6.	Copper corrosion (3 h at 100°C)	ASTM D130	Rating	1a	1a	1a	1a	1a	1a	1a	-	-
7.	Water by distillation	ASTM D95	vol. %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-
8.	Water content	ISO 12937	$mg kg^{-1}$	72	99	114	92	104	96	100	-	-
9.	Sediment by extraction	ASTM D473	mass %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-
10.	Carbon residue on 10% bottoms	ASTM D189	mass %	<0.1	<0.1	<0.1	<0.1	<0.1	0.10	0.10	-	-
11.	Density at 15°C	ASTM D4052	$kg L^{-1}$	0.8451	0.8479	0.8477	0.8478	0.8479	0.8479	0.8479	-	-
12.	Acid number	ASTM D664	mg KOH g^{-1}	0.04	0.06	0.05	0.07	0.06	0.07	0.07	-	-
13.	Electrical conductivity	ASTM D2624	$pS m^{-1}$	512	537	817	782	809	815	559	-	-
14.	Physical distillation at 95% recovered volume	ASTM D86	°C	362	358	359	358	358	357	358	-	-
15.	Cetane number	ASTM D6890	-	52.0	53.6	54.5	53.4	55.0	53.7	52.9	-	-
16.	Lubricity	ASTM D6079	µm	357.5	186.5	164.5	240.5	178.0	308.0	174.0	-	-
17.	Total sulphur	ASTM D5453	$mg kg^{-1}$	408	372	372	365	361	367	374	-	-

Knothe, G and Dunn, R O (2001). Biofuels derived from vegetable oils and fats. *Oleochemical manufacture and applications*. Gunstone, F D; and Hamilton, R J,eds. Sheffield Academic Press; p. 106-163.

Knothe, G (2010). Biodiesel lubricity and effect of biodiesel on lubricants. *The Biodiesel Handbook*, 2nd eds. Knothe, G; Krahl, J and Gerpen J V, eds. AOCS Press; p. 219-229.

Kushairi, A (2018). Malaysian oil palm industry performance 2017 and prospects for 2018. Palm Oil Economic Review and Outlook Seminar, Putrajaya, 18 January 2018.

Mittelbach, M and Remschmidt, C (2004). Fuel properties, quality specifications and fuel analysis for biodiesel and fossil diesel. *Biodiesel the Comprehensive Handbook*. Mittelbach, M and Remschmidt, C eds. p.109-83.

Nursyairah, J; Lau, H L N; Loh, S K; Rusnani, A M; Daryl, J T; Yung, C L; Ropandi, M; Wan Hasamudin, W H; Puah, C W; Yahaya, H; Noraida, O; Astimar, A A and Lim, W S

TABLE 6. PROPERTIES OF B10 DIESEL E

	Property	Test method	Unit	Diesel E	E1	E2	E3	E4	E5	E6	E7	E8
1.	Colour (ASTM)	ASTM D1500	-	L0.5	L0.5	L0.5	L0.5	L0.5	L0.5	L1.0	L0.5	L0.5
2.	Ash	ASTM D482	mass %	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001
3.	Cloud point	ASTM D2500	°C	7	8	9	7	8	7	7	9	10
4.	Flash point	ASTM D93	°C	65.0	68.0	67.0	67.0	70.0	68.0	69.0	62.0	69.0
5.	Kinematic viscosity at 40°C,	ASTM D445	$mm^2 s^{-1}$	3.196	3.295	3.295	3.284	3.290	3.290	3.287	3.312	3.313
6.	Copper corrosion (3 h at 100°C)	ASTM D130	Rating	1a	1a	1a	1a	1a	1a	1a	1a	1b
7.	Water by distillation	ASTM D95	vol. %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
8.	Water content	ISO 12937	$mg kg^{-1}$	88	122	122	101	116	110	108	140	110
9.	Sediment by extraction	ASTM D473	mass %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
10.	Carbon residue on 10% bottoms	ASTM D189	mass %	<0.1	0.10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11.	Density at 15°C	ASTM D4052	$kg L^{-1}$	0.8554	0.8572	0.8571	0.8572	0.8572	0.8572	0.8572	0.8567	0.8573
12.	Acid number	ASTM D664	$mg KOH g^{-1}$	<0.02	0.04	0.02	0.04	0.03	0.04	0.04	0.04	0.04
13.	Electrical conductivity	ASTM D2624	$pS m^{-1}$	685	642	845	842	879	922	635	1219	1146
14.	Physical distillation at 95% recovered volume	ASTM D86	°C	369	363	366	362	362	362	366	364	364
15.	Cetane number	ASTM D6890	-	52.3	53.3	53.0	52.6	52.6	53.1	54.4	54.4	53.8
16.	Lubricity	ASTM D6079	µm	369.5	166.5	152.0	309.5	165.5	317.5	175.0	166.5	174.0
17.	Total sulphur	ASTM D5453	$mg kg^{-1}$	288	263	261	259	258	258	257	251	253

TABLE 7. PROPERTIES REGULATED IN 4(1)(B) OF THE ENVIRONMENTAL QUALITY (CONTROL OF PETROL AND DIESEL PROPERTIES) REGULATIONS 2007

	Property	Unit	Limit
1.	Density at 15°C	$kg L^{-1}$	0.81-0.87
2.	Cetane number or cetane index	-	49 min
3.	Physical distillation at 95% recovered volume	°C	370 max
4.	Total sulphur	$mg kg^{-1}$	500 max

Source: ILBS (2014).

(2017). National biodiesel implementation in Malaysia: An update. *Palm Oil Engineering Buletin*, 125: 21-25.

Sheaves, B (2001). Biodiesel fuels. *Allpar Guest Editorial*.

Yung, C L; Lau, H L N and Choo, Y M (2013). Physico chemical properties of biodiesel produced from *Jatropha curcas* oil and palm oil. *J. Oil Palm Res.*, 25: 159-164.

Yung, C L; Loh, S K; Lim, W S and Choo, Y M (2016). Malaysian B5 implementation and its quality. *J. Oil Palm Res.*, 28: 331-343.