

THE COLD FLOW PROPERTIES OF PALM BIODIESEL FOR DIESEL BLENDS MANDATE IN MALAYSIA'S HIGHLANDS

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ABSTRACT

Greenhouse gas emission from burnt fossil fuels in transportation leads to global warming. Therefore, biodiesel which is believed to help in reducing carbon dioxide (CO₂) emission has been widely used as renewable energy that will replace diesel fuel. Biodiesel of 7% in diesel or B7 has been accepted worldwide to be the automotive fuel. In the last decade, most countries that implemented biodiesel program have gradually increased its biodiesel blending ratio above 7% for economic and environmental reasons. Malaysia has also announced the implementation of B20 starting January 2020. However, the biodiesel mandate in Malaysia's highlands was maintained at B7 because of the concern on low temperature vehicle operability. This study focuses on the cold flow properties of the blended diesel fuels and the quality of the palm biodiesel for the national biodiesel program. The monoglycerides and the water content in the biodiesel were evaluated in relation to cold temperature fuel performance. Cloud point (CP) and cold filter plugging point (CFPP) of B7 diesel sold at highlands were found below the lowest ambient temperature recorded at highlands for the past 10 years. Both CP and CFPP of Euro 5 diesel were lower than Euro 2M diesel. A 41-months survey of the monoglycerides and the water contents in the palm biodiesel indicated that the palm biodiesel used in Malaysia's biodiesel mandate meets both the EN14214:2019 and the Malaysian Standard MS2008:2014 specifications. CP and CFPP of the blended fuels increase with the increase of biodiesel blending ratio. Based on the study, it is anticipated that B20 could be introduced at Malaysia's highlands without any problem.

Keywords: biodiesel, CFPP, CP, monoglyceride content, palm biodiesel, water content.

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INTRODUCTION

The search of environmental-friendly and renewable energy sources to meet the worldwide energy demand has become immensely important to address global warming and climate change issues. The development of liquid biofuels has been seen to

be favourable as a substitute to fossil fuels. Biodiesel or mono-alkyl esters of long-chain fatty acid derived from vegetable oils or animal fats, has been used as the diesel replacement without much technical studies or being supported by its suitability studies (Bari and Hossain, 2019; Graboski and McCormick, 1998; Javed and Anurag, 2014). Biodiesel has rapidly emerged as one of the fastest growing alternative fuels in the world attributed by its clean emissions profile, ease of use for transport and many other benefits (Abed *et al.*, 2019; Ali *et al.*, 2016; Ayhan, 2007). The first internal combustion engine developed by Rudolf Diesel in 1900 was also based on food crops (biodiesel) (Ziolkowska, 2018). When crude oil was discovered a few years later, vegetable oil-based biofuel became irrelevant but resurfaced

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later due to oil crisis in the 1970's. Based on data by Organization for Economic Co-operation and Development (OECD) and Food and Agriculture Organization (FAO) (2020), the global biodiesel production from 2016-2018 stood at 43.1 billion litres with projected growth of 0.1% to reach 44 billion litres by 2028. The main driver for the increase of biodiesel usage is due to the government's mandate of some countries like Indonesia and Malaysia.

The research of renewable biofuel from palm oil in Malaysia was inspired in 1982. The biofuel was produced by converting palm oil into biodiesel (B100) or palm methyl ester (PME) via transesterification process (Choo *et al.*, 1997). Choo *et al.* (2005) reported that PME had been thoroughly examined, tested and proven as a superior diesel substitute and gained worldwide acceptance. There are 19 operational biodiesel plants in Malaysia with a total production capacity of 2.2 million tonnes per year (Parveez *et al.*, 2020).

Biodiesel can be produced from various feedstock such as palm, rapeseed, soybean, used cooking oil, tallow and others. Among all other oils, oil palm has the highest oil yield per cultivated area among all vegetable oils (Murphy, 2014). Thus, it is the most promising raw material for biodiesel production (Khairul and Manabu, 2018). Palm oil producing countries like Indonesia, Malaysia dan Thailand are aggressively implementing biodiesel program to encourage the use of renewable resources *i.e.*, palm oil domestically while reducing dependency on petroleum imports. Both Malaysia and Indonesia contributed to 85% of the global palm oil supply (Kushairi *et al.*, 2019).

Biodiesel has been mandated in Malaysia since 2010 starting with blending of 5% PME (B5) and gradually increased to 20% (B20) in January 2020. The implementation of B30 program in Malaysia is expected by 2025 (Ministry of International Trade and Industry, 2020). On the other hand, Indonesia had implemented B20 program in January 2016 and recently increased the mandate to B30 starting January 2020 (Agus *et al.*, 2019; Ministry of Energy and Mineral Resources, 2014). The increase in domestic consumption of palm oil through biodiesel program could help to absorb the surplus palm oil in the market as a result of the European Union's proposal to phase out palm oil-based biofuels by 2030 [Commission Delegated Regulation (2019) EU 2019/807]. There are two grades of diesel available at retail stations in Malaysia which are B10 (blends of 10% v/v palm biodiesel with 90% v/v diesel petroleum) with Euro 2M diesel (E2B10) and B7 (blends of 7% v/v palm biodiesel with 93% diesel petroleum) with Euro 5 diesel (E5B7). E5B7 is an optional diesel fuel sold at selected stations across all states throughout the country. B20 with Euro 2M diesel (E2B20) has been implemented at certain locality to replace E2B10 beginning January 2020.

Due to the concern on low temperature vehicle operation at cold places, the retail stations at highlands have been exempted from selling E2B10 but only supply B7 with Euro 5 diesel (E5B7) and Euro 2M diesel (E2B7).

In terms of technical performance, biodiesel has its limitation of low temperature flow characteristics which may lead to clogging of fuel filters and/or choking of the injectors (Dwivedi *et al.*, 2013). Researchers have found that high viscosity biodiesel at low temperature condition affects the engine performance, fuel consumption, emissions, and the engine components' function (Chen *et al.*, 2016; Hossain *et al.*, 2017). Concerning low temperature condition at cold places with potential temperature dropping below 15°C, three Malaysian highlands namely Cameron Highlands and Genting Highlands, in Pahang, and Kundasang, in Sabah, Malaysia have been exempted from selling B10 and continued to supply B7. Based on 10 years ambient temperature data recorded at Cameron Highlands by Meteorology Malaysia seismic station, there were trend of low temperature spikes from January to March each year with the temperature recorded between 11°C-13°C as shown in *Figure 1*. The lowest temperatures recorded at Cameron Highlands was 10.9°C in December 2007. There has not been any problem reported on using B7 diesel at Cameron Highlands since 2015 with the lowest ambient temperature ranging from 12°C-17°C. Since there is no meteorological station at Genting Highlands and Kundasang, no temperature data can be obtained.

The cold flow properties describe the behaviour of fuels under the influence of cold temperature and measured in terms of Cloud Point (CP), Cold Filter Plugging Point (CFPP) and Pour Point (PP). CP refers to the minimum temperature at which the first crystal is formed while PP is the lowest temperature below which a liquid loses its flow characteristics. The Malaysian diesel fuel standard (MS123) has specified the CP to be lower than 19°C (Department of Standard Malaysia, 2018; 2020). CFPP is often used to determine the low-temperature operability of a fuel that can be used to forecast the lowest temperature at which the fuel will flow freely through fuel filters in a diesel engine system (Hamon *et al.*, 1994; Zöldy, 2019).

The quality of the blending stock is important to ensure a problem-free biodiesel program. In Malaysia, the final diesel fuel blends shall meet the Malaysian Standard for Diesel Fuel (MS 123-4:2020) which allows up to 20% of palm in biodiesel (Department of Standards Malaysia, 2020). It is equally important that the specifications of palm biodiesel must comply with MS 2008:2014 for biodiesel used in any blending purposes (Department of Standards Malaysia, 2014). The MS 2008:2014 is equivalent to European Biodiesel

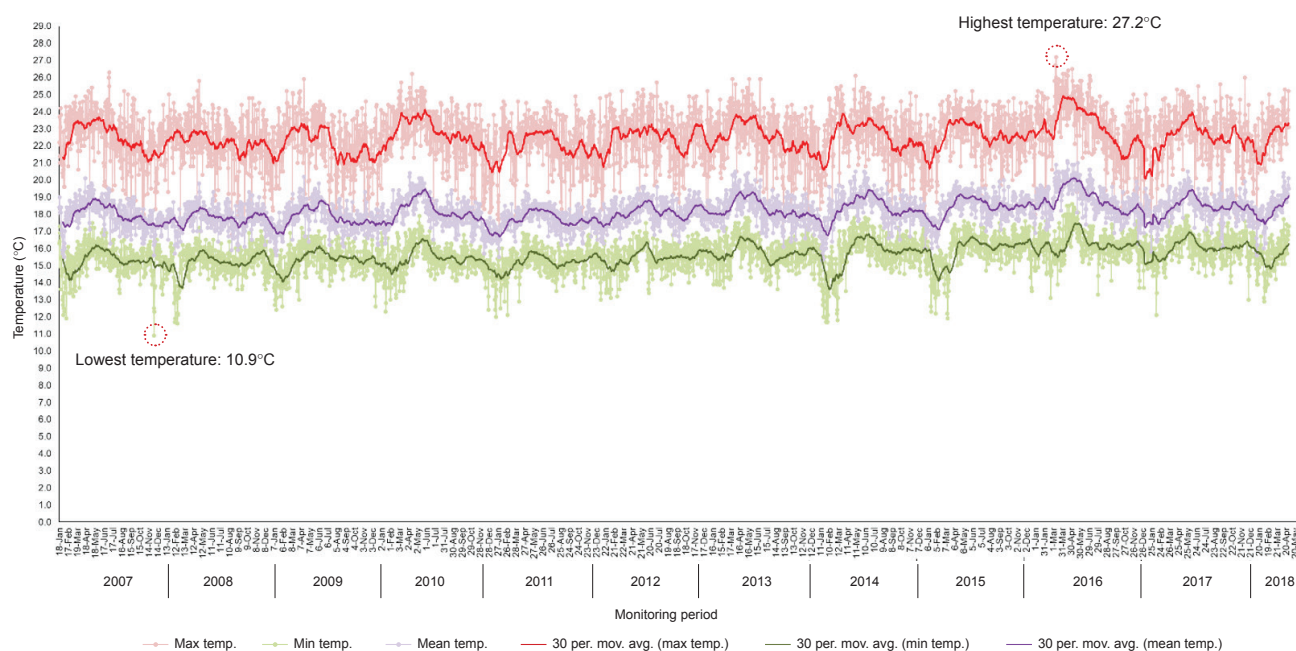


Figure 1. Average ambient temperature at Cameron Highlands from January 2007 to May 2018.

Standard (EN 14214) with tightened parameter on oxidative stability of 10 hr minimum induction period (European Standard, 2008).

The monoglycerides content and the water content in biodiesel are associated with the fuel precipitation and storage issue while using biodiesel. The monoglycerides content is crucial especially when the biodiesel blended fuel is used at low temperature condition that may lead to fuel filter plugging (Van Gerpen *et al.*, 1997). The presence of excessive water in fuels may cause damage to the fuel-injection system as well as corrosion in storage tanks. The hygroscopic nature of biodiesel could lead to an increase of the soluble water content during transportation and storage (Ferella *et al.*, 2010; Oliveira *et al.*, 2008). This stringent fuel specifications must be strictly followed to avoid any negative effects of using biodiesel in the internal combustion engine system.

This article discussed the cold flow properties of biodiesel blended fuels and quality of palm biodiesel supplied for national biodiesel program with special focus on monoglycerides and water contents. The CP, CFPP and PP of cold flow properties for B10, B20 and B30 were also investigated.

MATERIALS AND METHOD

The study was divided into three parts. First, samplings of B7 diesel were carried out at all three Malaysia’s highlands (Cameron Highlands, Genting Highlands and Kundasang), then B7 diesel samples were analysed for cold flow properties. Second, collection of data for monoglyceride content and water content of palm biodiesel (PME) supplied for

national biodiesel program was done by reviewing the quality of PME in terms of these two parameters. Finally, poor quality of B7 diesel with high CFPP and CP, and PME containing high monoglyceride content were selected for higher biodiesel blending and further assessed for CP and CFPP of the blending.

Sampling of B7 Diesel

Sampling of B7 diesel fuels from retail stations was carried out in order to understand the behaviour of cold flow properties of B7 diesel fuel in three highlands. B7 diesel namely Euro 2M (500 ppm max. sulphur) and Euro 5 (10 ppm max. sulphur) were collected from 12 retail stations at all three Malaysia’s highlands. Table 1 summarises the sample collected from all three highlands. Three rounds of sampling were carried out at all retail stations in the highlands; two retail stations at Genting Highlands, five stations at Cameron Highlands and five stations at Ranau and Kundasang, Sabah, respectively. A total of 43 B7 samples were collected of which 15 samples obtained were from 14-19 May 2018 for

TABLE 1. SAMPLES COLLECTED FROM HIGHLANDS

Highland	Euro 2M (500 ppm max. of sulphur)	Euro 5 (10 ppm max. of sulphur)
Cameron Highlands	C1, C2, C4, C6 and C8	C3, C5 and C7
Genting Highlands	G1 and G2	-
Kundasang/Ranau	K1, K2, K3, K4 and K5	-

sampling 1, 14 samples collected from 16-18 July 2018 for sampling 2 and from 10-13 September 2018 for sampling 3, respectively. Sample from one of retail stations located at Cameron Highland (C8) was unable to be collected during samplings 2 and 3 due to the inability of the station to provide the biofuel.

All samples were analysed based on its cold flow properties such as CP, CFPP and PP according to the ASTM D2500, ASTM D97 (ASTM International 2011; 2017) and EN 116 (European Standard, 2015), respectively. Each analysis was carried out in triplicate with the mean results reported.

Data Collection of Palm Biodiesel

Two important parameters *i.e.*, monoglycerides content and water content of palm biodiesel were monitored to ensure the quality of the final blended fuels was at its desirable quality prior to blending. Data of these two parameters was collected from their respective Certificate of Assurance (CoA) and analysed to get an overview of the quality of biodiesel supplied for national biodiesel program in Malaysia. Data collection was done for a period of 41 months from January 2016 to May 2019 from 12 biodiesel producers involved in the supply chain of the national biodiesel program. A total of 4373 certificates were collected from PME delivery tankers from petroleum depots. The analyses on monoglycerides content and water content were carried out by each producer according to the EN14105 (European Standard, 2011) and ISO 12937 (ISO, 2000), respectively.

Preparation of B10, B20 and B30 Blended Fuels

Based on the analyses for cold flow properties of B7 diesel fuels and monoglycerides content of palm biodiesel properties, further evaluation was conducted to study the behaviour of cold flow properties of high palm biodiesel blends at relevant temperature reflecting Malaysia's cold condition. B7 diesel with high CFPP was bought from a retail station at Genting Highlands. The palm biodiesel with monoglycerides content of 0.61% (m/m) was obtained from one of the biodiesel producers. The blends of B10, B20, B30 were prepared by measuring a fixed volume of diesel and biodiesel, homogenised and stored in glass bottles at room temperature. The blended fuels were analysed for CP, CFFF and PP according to the methods described above.

RESULTS AND DISCUSSION

A total of 43 B7 samples were collected from 12 retail stations at Cameron Highlands, Genting Highlands and Kundasang. Out of which, 34 samples were E2B7 with the remaining, of E5B7. The biodiesel content for both E2B7 and E5B7 were validated and it was in the range of 6.68% v/v to 7.51% v/v as shown in *Figure 2*. The average biodiesel content was determined to be 7.09% v/v as compared to the maximum limit of 7.5% v/v. The measurement of biodiesel content is very much depending on the purity of biodiesel and standard diesel used for equipment calibration. Based on the results, the range of biodiesel

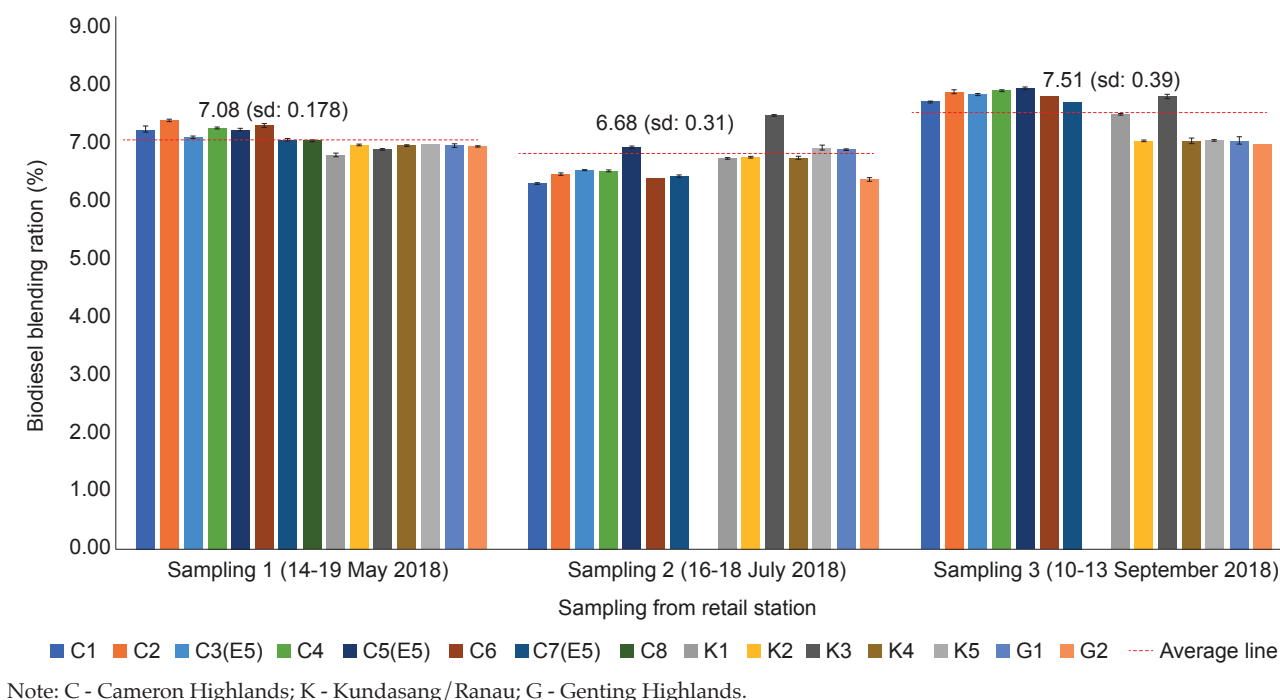


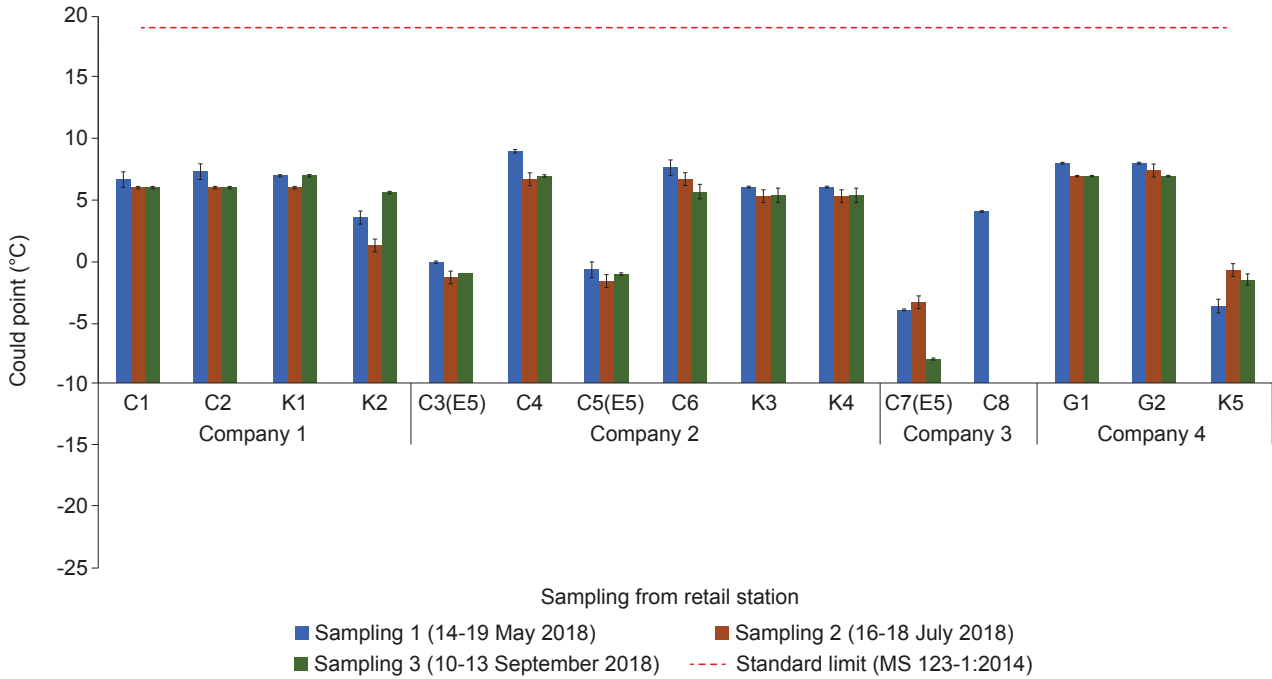
Figure 2. Biodiesel content in diesel sold at highland retail stations.

blending ratio is within 6.5%-7.5% v/v which falls within the acceptable range.

The samples were grouped based on the company and location, in which there are four brands representing petroleum companies in three highlands. *Figure 3* shows the CP of B7 samples collected from retail stations at highlands with the highest value of 9°C as compared to the maximum

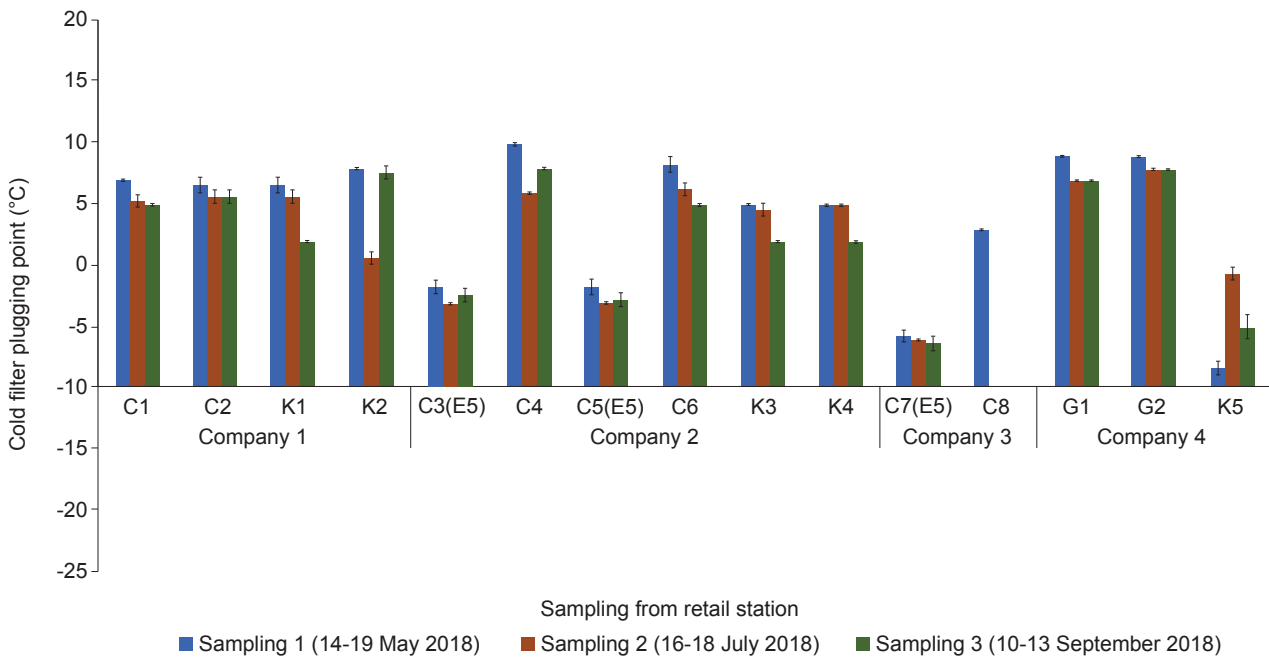
limit of 19°C as stipulated in MS 123:2018/2020. All CP of E5B7 was lower than E2B7 except for sample K5 which was below 0°C.

There was noticeable fluctuation of CFPP for all diesel fuel samples collected from retail stations at highlands as shown in *Figure 4*. In general, the CFPP of E5B7 samples was found ranging from -2°C to -7°C as compared to E2B7 from 1°C-10°C.



Note: C - Cameron Highlands; K - Kundasang/Ranau; G - Genting Highlands.

Figure 3. Cloud point of E5B7 and E2B7 from retail station at highlands.



Note: C - Cameron Highlands; K - Kundasang/Ranau; G - Genting Highlands.

Figure 4. Cold filter plugging point of E5B7 and E2B7 from retail station at highlands.

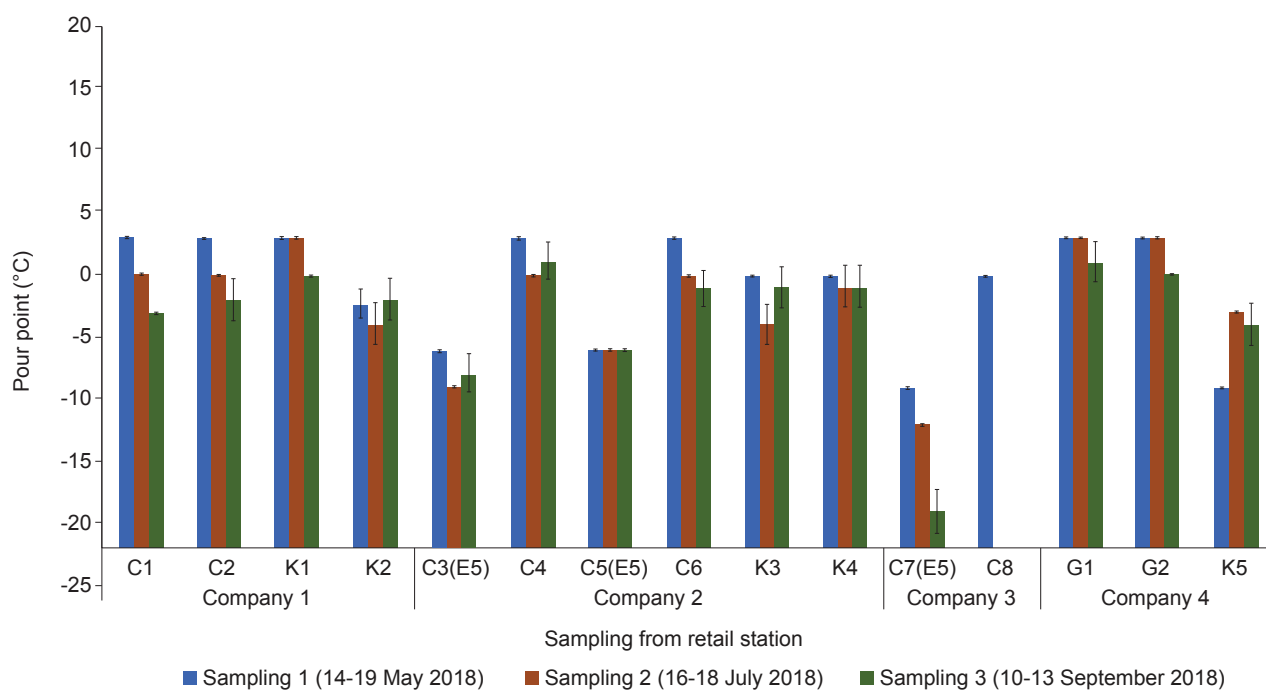
The samples from station C4 has the highest CFPP recorded at 10°C with similar trend observed for G1 and G2. *Figure 5* shows 32 samples of the diesel fuel having PP $\leq 0^\circ\text{C}$ where the lowest PP was -19°C from sample C7 (E5). A similar trend with CP can be seen for PP in which all E5B7 samples were below -5°C , lower than E2B7 except for K5. The wide range in variation of CP, CFPP and PP could be contributed by different sources of diesel supply of individual petroleum companies. There are four brands of retail stations at the highlands. Blending of biodiesel in diesel takes place at petroleum terminals via in-line blending facilities. The quality of diesel as main blending component is important to ensure a good cold flow property of blended fuel is achieved. In addition, the content of saturated fatty acids in biodiesel plays an important role in determining the CFPP and CP of the blended fuel (Knothe, 2005). The cold flow property of a normal grade PME varies between a narrowed range of 12°C - 15°C depending on its fatty acid composition. Based on the study, it is proven that the B7 fuels sold at retail stations at highlands has met the CP specification as stipulated in MS 123. Further investigation of CFPP revealed that all B7 fuels has CFPP that can withstand the coldest temperature ever experienced in Cameron Highlands.

As the tests of CP and CFPP were conducted in a laboratory atmosphere, it may not be accurately representing the actual vehicle running condition in the open environment. It is anticipated that with the latest common rail diesel technology, the return fuel to the diesel tank will raise the fuel temperature

above ambient temperature (unpublished data: Lau *et al.*, MPOB, 2020). Thus, the concern on fuel precipitation could only be verified through on-the-road field test in actual environment.

Apart from investigating the cold flow properties of blended fuel sold at highlands, the assessment on the quality of palm biodiesel supplied for the national biodiesel program was needed to ensure the blended fuel meets the standard requirement. Monoglycerides content in palm biodiesel (B100) is a crucial parameter to be monitored prior to blending with diesel. It is reported that the major cause of precipitate formation at low temperatures in palm biodiesel blended fuel is attributed to monoglycerides content (Tang *et al.*, 2008). *Figure 6* shows the monoglycerides content of palm biodiesel produced in Malaysia from January 2016 to May 2019. The yearly average of monoglycerides content of palm biodiesel was between 0.456% m/m to 0.505% m/m which meets the requirement of less than 0.7% m/m as stipulated in the MS 2008:2014. Monoglycerides content was widespread from 0.1% m/m to 0.69% m/m from the second half of 2017 until the first half of 2019 compared to those of narrower range prior to this, ranging from 0.2% m/m to 0.6% m/m. Statistically, changes of monoglycerides content is significant within collection period with $p > 0.05$.

Figure 7 shows the monoglycerides content of biodiesel by producer. The amount of biodiesel supplied by producer from January to June 2019 was within 100-6700 t month⁻¹ based on demand by the petroleum depots (unpublished data: Noraida



Note: C - Cameron Highlands; K - Kundasang/Ranau; G - Genting Highlands.

Figure 5. Pour point of E5B7 and E2B7 from retail station at highlands.

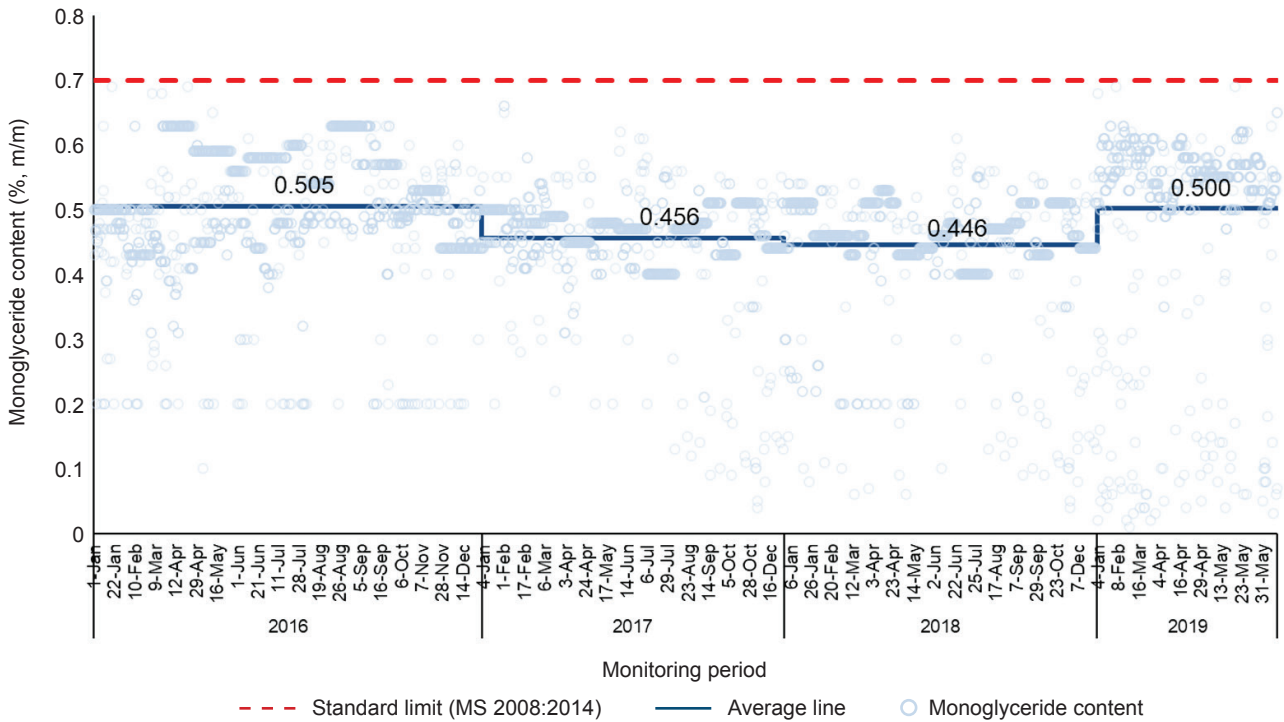


Figure 6. Monoglycerides content of palm biodiesel supplied to petroleum depots from January 2016 to May 2019.

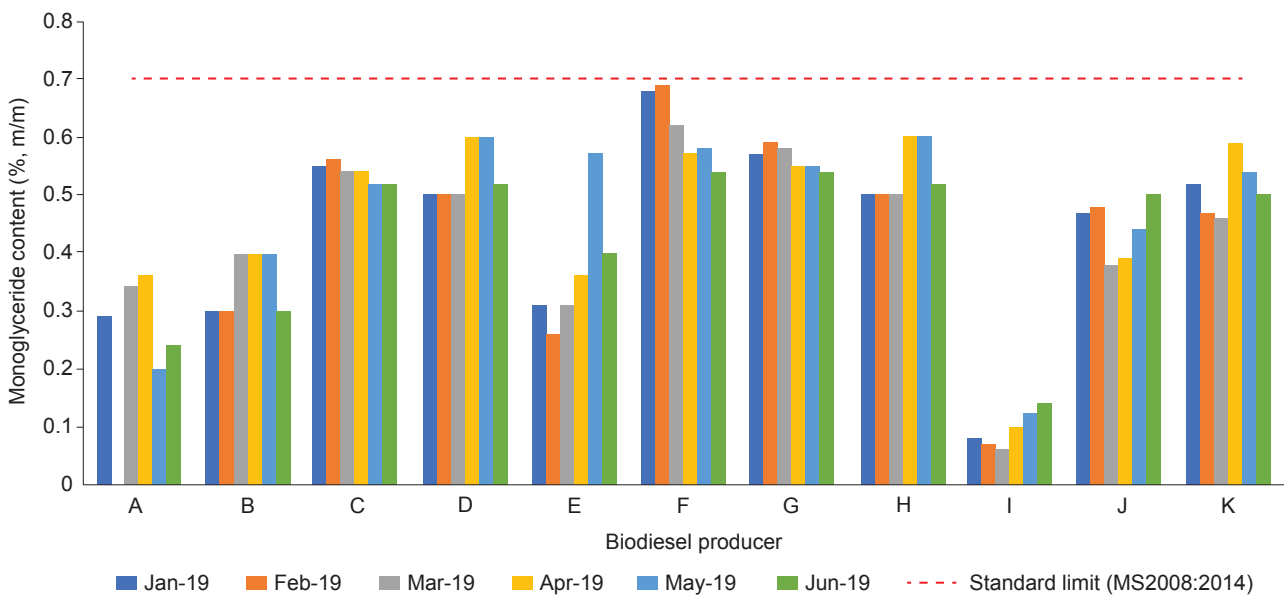


Figure 7. Monoglycerides content of palm biodiesel by different producer from January to June 2019.

et al., MPOB, 2021). In actual practice, biodiesel from different producers is commingled in the same storage tank at blending terminals. This means that the biodiesel with high monoglycerides content will be diluted with those of low monoglycerides content. Biodiesel with very low monoglycerides content of less than 0.1% can be achieved by incorporating additional distillation process of biodiesel which allows production of high-quality product without diglycerides and triglycerides, and only containing traces of monoglycerides.

The unreacted neutral oils left in the biodiesel such as mono-, di-, and triglycerides, might have high melting points and very low solubilities (Poalo *et al.*, 2013). Owing to this, their presence especially the monoglycerides could form solid residues when exposed to cold temperature. As such, the properties of biodiesel will be affected at low temperature (Aisyah *et al.*, 2018; Imam *et al.*, 2019). Monoglycerides content in pure palm biodiesel needs to be investigated for the use of B30.

Besides monoglycerides content, precipitate formation was also found to be influenced by water content in biodiesel (Plata *et al.*, 2015). Biodiesel is known to have high affinity of absorbing moisture *i.e.*, 6.5 to nine times and retaining water than petroleum diesel (He *et al.*, 2007; Patricia *et al.*, 2012). High moisture in biodiesel could possibly be attributed by inadequate drying during processing and absorption of atmospheric moisture during storage. Water content of biodiesel is correlated with surrounding temperature. Water precipitation and condensation might occur when the moisture level in biodiesel falls beyond its saturation point leading to accumulation of water that settles at the bottom of storage tank. High water content in biodiesel or diesel is also associated with microbial growth which may result in fuel filter plugging, and corrosion of fuel tank and fuel delivery system (Van Gerpen, 2005). As illustrated in *Figure 8*, the water content of palm biodiesel supplied for blending purposes ranging between 200–350 mg kg⁻¹, *i.e.*, below the maximum limit of <500 mg kg⁻¹ as required under MS 2008:2014. The average water content in biodiesel for 2016, 2017, 2018 and 2019 were below 300 mg kg⁻¹ or 240, 243, 242 and 282 mg kg⁻¹ respectively. As the storage of biodiesel at blending depots is typically less than seven days, the moisture content in biodiesel has maintained below the specified limit before it is blended into diesel.

To evaluate on the worst-case scenario, the B10, B20 and B30 fuels were prepared by blending E2B7 diesel with high CFPP of 8°C and PME that contains the highest average monoglycerides content of 0.61% m/m. The properties of E2B7 diesel and PME are summarised in *Tables 2* and *3*, respectively.

The CFPP and CP of blended fuels (B10, B20 and B30) will increase with the increase of biodiesel blending ratio as shown in *Figure 9*. The same observation was reported in most previous literatures *e.g.*, José *et al.* (2019); Kassem and Camur (2017); Verma *et al.* (2016). The viscosity of blended fuel was also directly proportional to biodiesel blending ratio in which the increasing trend of viscosity can be observed from B7 to B30. The higher the biodiesel concentration, the more viscous the resulted fuel would be (Alptekin and Canakci, 2008; Kiran *et al.*, 2018; Samuel *et al.*, 2019). CP of all blended fuels (B7, B10, B20 and B30) were well below the limit of 19°C as in the MS 123:2018/2020. As shown in *Figure 9*, B7 and B10 should be safe to be used in the highlands as its CP and CFPP were below the lowest recorded temperature of 10.9°C. For B20, both CP and CFPP are close to the lowest temperature in the highlands. With the increase of 30% v/v palm biodiesel in diesel, the CP of 10°C was approaching the lowest temperature of 10.9°C while the CFPP has increased significantly above the lowest temperature in the highlands. This might indicate the use of B30 could contribute to the vehicle's cold operability problems. Interestingly, CFPP of B100 does not change much compared to B30 but the CP increased from 10°C (B30) to 16°C. To consider actual fluctuation of temperature in the highlands, both CFPP and CP of B20 were below 10°C which suited the minimum temperature range of 12°C–17°C at Cameron Highlands (*Figure 1*). Based on the results, B20 could be used at Malaysia's highlands as its CFPP and CP are below the minimum temperature at highlands over the last 10 years. However, as the lowest temperature had once reached 10.9°C, the

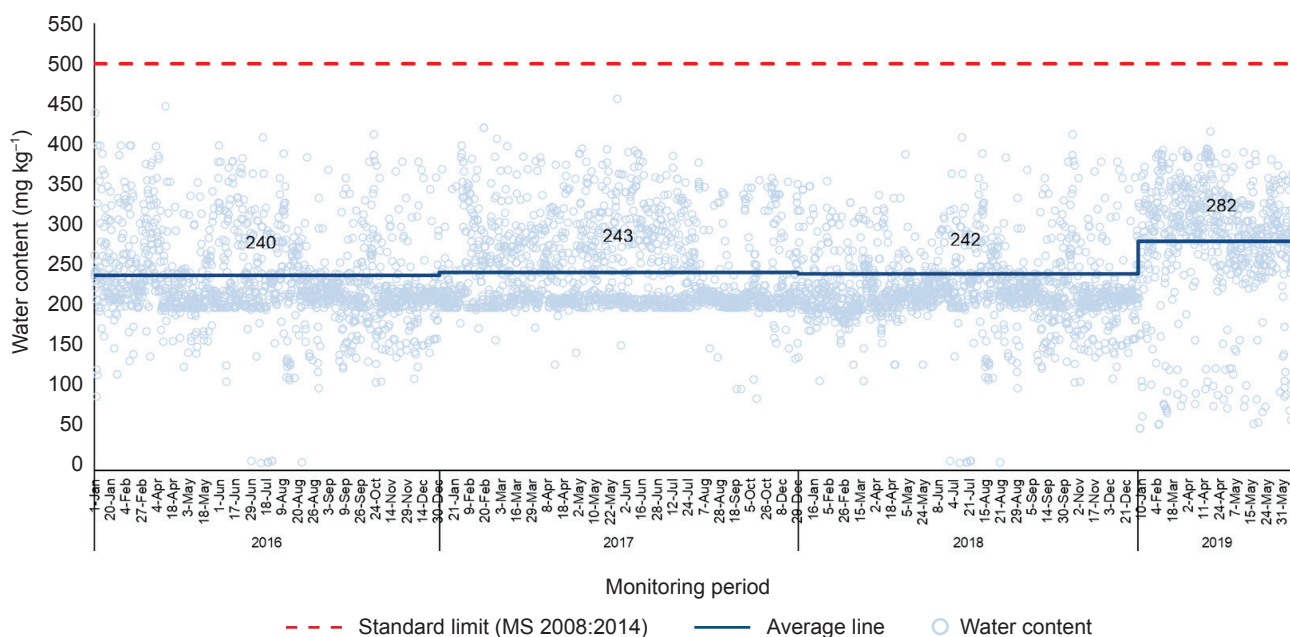


Figure 8. The water content of palm biodiesel supplied to petroleum depots from January 2016 to May 2019.

TABLE 2. PROPERTIES OF E2B7 DIESEL

Parameter	Unit	Method	Specification	Result
Ester content	%	EN 14103	-	6.98
CFPP	°C	EN 116	-	8
CP	°C	ASTM D2500	19.0 max	7.7
PP	°C	ASTM D97	-	1
Viscosity	mm ² s ⁻¹	ASTM D445	1.5-5.8	3.086
Density at 15°C	g cm ⁻³	ASTM D4052	0.81-0.87	0.8376
Flash point	°C	ASTM D93	60 min	68.5

Note: CFPP - cold filter plugging point; CP - cloud point; PP - pour point.

TABLE 3. PROPERTIES OF PALM BIODIESEL

Parameter	Unit	Method	Specification	Result
Ester content	% m m ⁻¹	EN 14103	96.5 min	98.05
Density @ 15°C	kg m ⁻³	EN ISO 12185	860-900	874.2
Flash point	°C	EN ISO 2719	120 min	178
Water content	mg kg ⁻¹	EN ISO 12937	400 max	365
Acid value	mg KOH g ⁻¹	EN 14104	0.50 max	0.4
Iodine value	g iodine 100 g ⁻¹	EN 14111	110 max	50.3
Total contamination	mg kg ⁻¹	EN 12662	24 max	21
Oxidation stability, 110°C	hr	EN 15751	8.0 min	20.8
Cloud point	°C	ASTM D2500	-	15
Cold filter plugging point, CFPP	°C	EN 116	15 max	13
Breakdown of MG:		GC		
MG-C16:0				0.3
MG-C18:0				0.03
MG-C18:1, C18:2, C18:3				0.25

Note: CFPP - cold filter plugging point; MG-C - monoglyceride content.

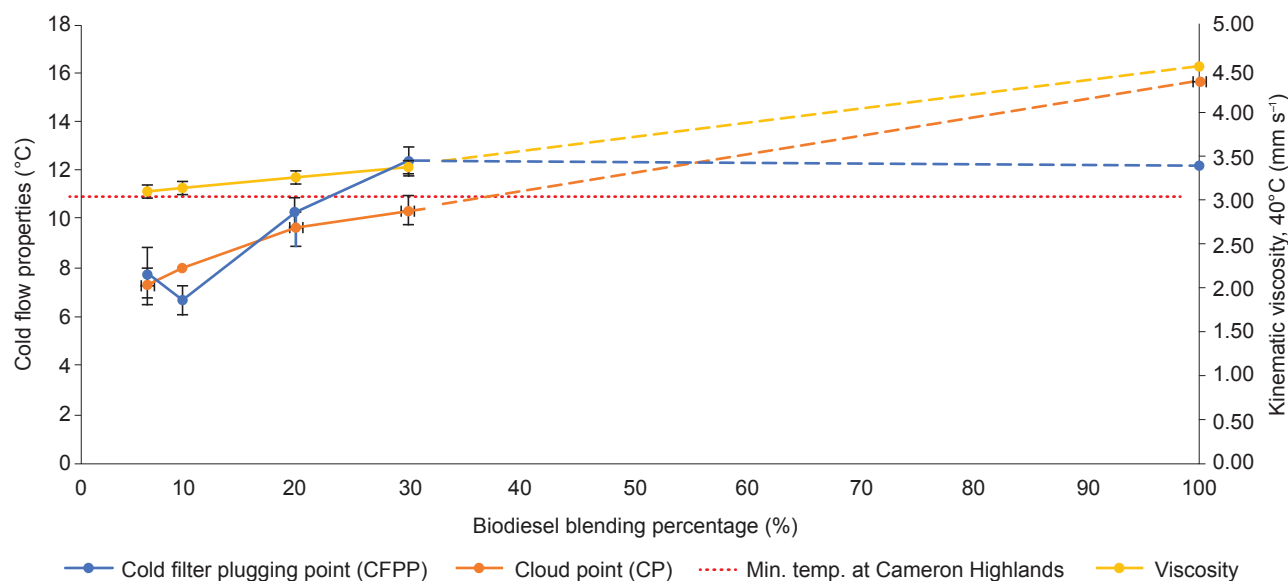


Figure 9. Cold flow properties and kinematic viscosity of blended fuel.

use of B20 needs to be approached with caution as precipitation might happen and could lead to potential filter plugging incident; that to be further confirmed by vehicle testing. For any increase of biodiesel blending in diesel at low temperature conditions, the specifications of CP and CFPP of the blended fuel shall be set on par with the minimum ambient temperatures. This is to ensure no low operability issues of long running vehicles in the highlands.

Table 4 shows the standard specification of cold flow properties of the blended diesel fuel for some countries. The cold flow properties of a particular fuel are of concern for temperate countries as compared to tropical countries like Malaysia, as the extreme temperature changes will impact the fuel properties. Some of the countries have specified the CFPP and CP in the standard according to the specific climatic environments like EN590. Hence, the existing diesel standard, MS123 is significant to be improved, which is to include CFPP to cater the use of the high biodiesel blends in the highlands, in

addition to CP with maximum limit of 19°C. This is to ensure that the cold operability issues of the diesel vehicles using the high biodiesel blend have been taken into account under the standard for future national biodiesel implementation plan.

CONCLUSION

Periodical monitoring of the critical parameters in diesel fuel and biodiesel are essential to ensure the best quality of blended fuels to be delivered and used without any problems across the nation. Concerning the cold operability issues using the biodiesel blends, cold flow properties *i.e.*, CP and CFPP of B7 diesel fuel was investigated to understand the behaviour of these parameters in the B7 diesel fuel sold in the highlands. The B7 diesel fuel samples collected from retail stations at the highlands have been validated to contain 6.5% v/v to 7.5% v/v of palm biodiesel and have been used for this study. All the samples showed the CP of B7 were within

TABLE 4. STANDARD SPECIFICATION OF DIESEL/ BIODIESEL BLENDS FOR COLD FLOW PROPERTIES OF SOME OF THE COUNTRIES

Country	Malaysia	Indonesia	Europe (CEN)		America		German	Japan	Brazil
Standard	MS 123-1:2018/2020	CN 48: SK 978/2013 CN 51 or above: SK 3675/2006	EN 590:2013 <i>Temperate climatic zones</i>	<i>Arctic climatic zones</i>	ASTM D975	ASTM D7467 (B6 - B20)	DIN 51605	JIS K 2204	ANP 42/2009
CP, max	19°C ASTM D2500	18°C D97	-	-10°C (Class 0) -16°C (Class 1) -22°C (Class 2) -28°C (Class 3) -34°C (Class 4) EN 23015:1994	Only guidance provided D2500	Only guidance provided D2500	-	-	-
CFPP, max	-	-	5°C (Class A) 0°C (Class B) -5°C (Class C) -1°C (Class D) -15°C (Class E) -20°C (Class F) EN 116:199	-20°C (Class 0) -26°C (Class 1) -32°C (Class 2) -38°C (Class 3) -44°C (Class 4) EN 116:1997	Only guidance provided D4539/ D6371	Only guidance provided D4539/ D6371	Depends on regions and month	Depends on regions and month ASTM D6371	0°C-12°C Depends on regions and month ASTM D6371
PP, max	-	-	-	-	-	-	-	-	-

Note: CFPP - cold filter plugging point; CP - cloud point; PP - pour point.

the maximum limit of 19°C as stipulated in MS 123:2018/2020 with the highest value of 9°C. The CFPP of E5B7 was found lower compared to E2B7 with the highest CFPP recorded at 10°C. Besides B7's cold flow properties, the monoglycerides and water contents of palm biodiesel supplied for the Malaysia biodiesel program have also been analysed, as these parameters contribute to the formation of precipitates at low temperatures. Both monoglycerides and water contents were found to meet the stringent requirements as stipulated under MS 2008:2014 for the period of 42 months.

Conceiving the worst-case scenario on the behaviour of cold flow properties, CP and CFPP of high palm biodiesel blend fuels was assessed to predict its usability in cold areas such as highlands. Based on the evaluation, the blending percentage of biodiesel in diesel had correlated with the CFPP and CP of the blended fuel. The CFPP and CP had increased with the increase of biodiesel content in diesel. The CP and CFPP of B7, B10 and B20 were below the lowest temperature of 10.9°C in the highlands while CFPP of B30 was 12°C, above the lowest temperature. This indicates that biodiesel up to 20% v/v can be used in the highlands, whereas the use of B30 may cause some problems to vehicles.

With the strong correlation between biodiesel percentage and CFPP, this parameter is considered as a better indicator for blended fuel as compared to CP of diesel fuel at cold climate usage. Thus, the specification of CFPP could be introduced with a maximum limit of 10°C to allow the use of B20 in the existing MS123 diesel standard, as this parameter is also included in the EU standards.

From the assessment of cold flow properties, biodiesel blends up to B20 are predicted to be suitable for the diesel vehicles operating at Malaysia's highlands as its CFPP was below the lowest recorded temperature of highlands. This can be confirmed through engine testing in future studies.

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REFERENCES

Abed, K A; Gad, M S; El Morsic, A K; Sayedd, M M and Abu Elyazeede, S (2019). Effect of biodiesel fuels on diesel engine emissions. *Egypt. J. Pet.*, 28: 183-188.

Aisyah, L; Wibowo, C S; Bethari, S A; Ufidian, D and Anggarani, R (2018). Monoglyceride contents in biodiesel from various plants oil and the effect to low temperature properties. *IOP Conf. Ser.: Mater. Sci. Eng.*, 316: 012023. DOI: 10.1088/1757-899X/316/1/012023.

Agus, S; Anindhita, I R A F; La, O M A W and Adiarso (2019). Indonesia Energy Outlook 2019 - The Impact of Increased Utilisation of New and Renewable Energy on the National Economy. *Badan Pengkajian dan Penerapan Teknologi (BPPT)*. Jakarta, Indonesia. p. 60.

Alptekin, E and Canakci, M (2008). Determination of the density and the viscosities of biodiesel-diesel fuel blends. *Renew. Energy*, 33(12): 2623-2630.

Ali, O M; Mamat, R; Abdullah, N R and Abdullah, A A (2016). Analysis of blended fuel properties and engine performance with palm biodiesel-diesel blended fuel. *Renew. Energy*, 86: 59-67.

ASTM International (2011). ASTM D2500-11. Standard Test Method for Cloud Point of Petroleum Products. ASTM International, West Conshohocken.

ASTM International (2017). ASTM D97. Standard Test Method for Pour Point of Petroleum Products. ASTM International, West Conshohocken.

ASTM International (2017). D2500-17. Standard Test Method for Cloud Point of Petroleum Products and Liquid Fuels. ASTM International, West Conshohocken.

Ayhan, D (2007). Importance of biodiesel as transportation fuel. *Energy Policy*, 35: 4661-4670.

Bari, S and Hossain, S N (2019). Performance and emission analysis of a diesel engine running on palm oil diesel (POD). *Energy Procedia*, 160: 92-99.

Chen, H; Guo, Q; Zhao, X and Xu, M (2016). Influence of fuel temperature on combustion and emission. *J. Energy Inst.*, 89: 231-239.

Choo, Y M; Ma, A N; Chan, K W and Yusof, B (2005). Palm diesel: An option for greenhouse gas mitigation in the energy sector. *J. Oil Palm Res.*, 17: 47-52.

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

Commission Delegated Regulation (2019). Commission Delegated Regulation (EU) 2019/807 (2019). http://data.europa.eu/eli/reg_del/2019/807/oj, accessed on 4 November 2020.

- Department of Standards Malaysia (2014). MS 2008:2014, Automotive Fuels – Palm Methyl Ester (PME) for Diesel Engines – Requirement and Test Methods (First revision). Department of Standards Malaysia, Ministry of Science, Technology and Innovation, Cyberjaya.
- Department of Standards Malaysia (2018). MS 123-1:2018, Malaysian Standard – Diesel – Specification – Part 1: Euro 2M (Fifth revision). Department of Standards Malaysia, Ministry of Science, Technology and Innovation, Cyberjaya.
- Department of Standards Malaysia (2020). MS 123-4:2020, Malaysian Standard – High PME Diesel Fuel – Specification – Euro 2M. Department of Standards Malaysia, Ministry of Science, Technology and Innovation, Cyberjaya.
- Dwivedi, G; Jain, S and Sharma, M P (2013). Diesel engine performance and emission analysis using biodiesel from various oil sources – Review. *J. Mater. Environ. Sci.*, 4: 434-447.
- European Standard (2008). EN 14214:2008 (E). Automotive Fuels - Fatty Acid Methyl Ester (FAME) for Diesel Engines - Requirement and Test Methods. European Standards, Brussels, Belgium.
- European Standard (2011). EN14105 Fat and Oil Derivatives - Fatty Acid Methyl Esters (FAME) - Determination of Free and Total Glycerol and Mono-, Di-, Triglyceride Contents. European Standard, Brussels, Belgium.
- European Standard (2015). EN 116 Diesel and domestic heating fuels – Determination of cold filter plugging points. European Standards, Brussels, Belgium.
- Ferella, F; Di Celso, G M; De Michelis, I; Stanisci, V and Veglio, F (2010). Optimization of the transesterification reaction in biodiesel production. *Fuel*, 89: 36-42.
- Fregolente, P B L; Fregolente, L V and Maciel, M R W (2012). Water content in biodiesel, diesel and biodiesel-diesel blends. *J. Chem. Eng.*, 57(6): 1817-1821.
- Graboski, M S and McCormick, R L (1998). Combustion of fat and vegetable oil derived fuels in diesel engines. *Prog. Energy Combust. Sci.*, 24: 125-164.
- Hamon, D; Damin, B and China, P (1994). New Diesel Low Temperature Operability Test - Agelfi Filtration Test. SAE Technical Paper 940081.
- He, B B; Thompson, J C; Routt, D W and Van Gerpen, J H (2007). Moisture absorption in biodiesel and its petro-diesel blends. *Appl. Eng. Agric.*, 23(1): 71-76.
- Hossain, A K; Smith, D I and Davies, P A (2017). Effects of engine cooling water temperature on performance and emission characteristics of a compression ignition engine operated with biofuel blend. *J. Sustain. Dev. Energy, Water Environ. Syst.*, 5: 46-57.
- ISO (2000). ISO 12937. Petroleum products – Determination of water – Coulometric Karl Fisher titration method. Geneva, Switzerland.
- Javed, A and Anurag, S (2014). Biodiesel as an alternative fuel for diesel engine - An overview. *Int. J. Appl. Eng. Res.*, 9(10): 1159-1168.
- Kassem, Y and Camur, H (2017). A laboratory study of the effects of wide range temperature the properties of biodiesel produced from various waste vegetable oils. *Waste Biomass Valor.*, 8: 1995-2007.
- Knothe, G (2005). Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. *Fuel Process. Technol.*, 86: 1059-1070.
- Kiran, R B; Rahul, T S, Kundla, S and Vardhan, G V (2018). Effects of blending on the properties of diesel and palm biodiesel. *IOP Conf. Ser.: Mater. Sci. Eng.*, 330: 012092. DOI: 10.1088/1757-899X/330/1/012092.
- Ministry of Energy and Mineral Resources (2014). MEMR Regulation No. 20/2014' Mandatory biofuel. Ministry of Energy and Mineral Resources (MEMR), Jakarta, Indonesia.
- Ministry of International Trade and Industry (2020). National Automotive Policy (NAP 2020). Ministry of International Trade and Industry, Malaysia. p. 57.
- Murphy, D J (2014). The future of oil palm as a major global crop: Opportunities and challenges. *J. Oil Palm Res.*, 26(1): 1-24.
- Oliveira, M B; Varanda, F R; Marrucho, I M; Queimada, A J and Coutinho, A P (2008). Prediction of water solubility in biodiesel with the CPA equation of state. *Ind. Eng. Chem. Res.*, 47: 4278-4285.
- OECD/FAO (2020). *OECD-FAO Agricultural Outlook 2020-2029*. https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook_19991142, accessed on 27 October 2020.

- Parveez, G K A; Elina, H; Loh, S K; Meilina, O; Kamalrudin, M; Mohd, N I Z B; Shamala, S; Zafarizal, A A H and Zainab, I (2020). Oil palm economic performance in Malaysia and R&D progress in 2019. *J. Oil Palm Res.*, 32(2): 159-190.
- Paryanto, I; Prakoso, T; Suyono, E A and Gozan, M (2019). Determination of the upper limit of monoglyceride content in biodiesel for B30 implementation based on the measurement of the precipitate in a biodiesel-petrodiesel fuel blend (BXX). *Fuel*, 258: 116104. DOI: 10.1016/j.fuel.2019.116104.
- Plata, V; Gauthier-Maradei, P and Kafarov, V (2015). Influence of minor components on precipitate formation and filterability of palm oil biodiesel. *Fuel*, 144: 130-136.
- Rodriguez-Fernández, J; Harnandez, J J; Calle-Asensio, A; Ramos, Á and Barba, J (2019). Selection of blends of diesel fuel and advanced biofuels based on their physical and thermochemical properties. *Energies*, 12: 2034. DOI: 10.3390/en12112034.
- Samuel, O D; Oreko, B U; Oyejide, J O; Idi, S; Ojo, S I and Fayomi, O S I (2019). Experimental and empirical study of diesel and biodiesel produced from blend of fresh vegetable and waste vegetable oil on density, viscosity, sulphur content and acid value. *J. Phy.: Conf. Ser.*, 1378: 042024. DOI: 10.1088/1742-6596/1378/4/042024.
- Tang, H; Salley, S O and Simon Ng, K Y (2008). Fuel properties and precipitate formation at low temperature in soy-, cottonseed-, and poultry fat-based biodiesel blends. *Fuel*, 87: 3006-3017.
- Verma, P; Sharma, M P and Dwivedi, G (2016). Evaluation and enhancement of cold flow properties of palm oil and its biodiesel. *Energy Rep.*, 2: 8-13.
- Van Gerpen, J (2005). Biodiesel processing and production. *Fuel Process. Technol.*, 86(10): 1097-1107.
- Van Gerpen, J H; Hammond, E G; Yu, L and Monyem, A (1997). Determining the influence of contaminants on biodiesel properties. SAE Technical Paper No. 971685.
- Zahan, K A and Kano, M (2018). Biodiesel production from palm oil. Its by-products, and mill effluent: A review. *Energies*, 11(8): 2132. DOI: 10.3390/en11082132.
- Ziolkowska, J R (2018). Introduction to biofuel and potentials of nanotechnology. *Green Nanotechnology for Biofuel Production* (Srivastava, N; Srivastava, M; Pandey, H; Mishra, P K and Ramteke, P W eds.). *Biofuel and Biorefinery Technologies*. Springer, Basel. p. 1-15.
- Zöldy, M (2019). Investigation of correlation between diesel fuel cold operability and standardized cold flow properties. *Period. Polytech. Transp. Eng.*, 49(2): 120-125. DOI: 10.3311/PPtr.14148.