Scientific Contributions Oil & Gas, Vol. 43. No. 2, August 2020: 81 - 90

SCIENTIFIC CONTRIBUTIONS OIL AND GAS

Research and Development Centre for Oil & Gas Technology

"LEMIGAS"

Journal Homepage:http://www.journal.lemigas.esdm.go.id

ISSN: 2089-3361, e-ISSN: 2541-0520

The Evaluation off Lubricant Performance in Light-and Heavy-Duty Diesel Engines in the Application of Biodiesel (B20)

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Manuscript received: May, 12th 2020; Revised: on July, 27th 2020
Approved: August, 30th 2020; Available online: September, 4th 2020

ABSTRACT

The use of biodiesel as fuel in light- and heavy-diesel engine vehicles in general will negatively affects the lubricant performance. the changes in lubricants properties during the use of B20 were investigated. Two type of vehicles engines were used, namely heavy duty and light duty diesel engines. The road test was carried out until 40,000 km, while the lubricant was drained and analysed only for 10,000 km of distances. The laboratory test was conducted to observe both fresh and used lubricants. The results show that the biodiesel dilutions were less than 2% both in light- and heavy-duty diesel engines. The kinematic viscosities of 4 samples of used lubricants in light-duty diesel engine were decreased in the ranges of 0.58 – 7.5%, while in heavy-duty diesel engines were 4.66-16.04% from the initial values. The decreasing of TBNs were less than 14% in light-duty diesel engine and fewer than 16% in heavy-duty diesel engine fuelled by biodiesel (B20). Meanwhile, the acidity of used engine oil was increased until 173% for light-duty diesel engine and 63% heavy-duty diesel engine compare to the initial values. The results show that the metal additives decreased while wear metal increased. According to this study, the increasing of wear metal (copper) in the used lubricants were less than 23% in light-duty diesel engine and lower than 26% in heavy-duty diesel engine fuelled by biodiesel (B20). Meanwhile, the lead contents of used engine oil were increased to 3.2 ppm in heavy-duty diesel engine and was not detected in light-duty diesel engine. After all, this work found that the lubricants exhibit good performances in the light- and heavy-duty diesel engines fuelled by B20. The changes of some critical properties were still in the acceptable values regarding to the specification as required in the SNI-7069-5 (2021).

Keywords: biodiesel, used lubricants, light-duty diesel engine, heavy-duty diesel engine.

How to cite this article:

M. Hanifuddin, M. Fibria, C.Y. Respatiningsih, S. Widodo, and Maymuchar, 2020, The Evaluation of Lubricant Performance in Light-And Heavy-Duty Engines in the Application of Biodiesel (B20), *Scientific Contributions Oil and Gas*, 43 (2) pp., 81-90.

INTRODUCTION

The application of biofuels in transportation, household, and industrial have continuously increased. The shortage of fossil fuels and the increase of environmental awareness become the main factor affecting this phenomenon. The implementation of biofuels as fossil fuel substitution in Indonesia is mandated in the Minister of Energy and Mineral Resources Regulation Number 12 (2015) concerning the third Amendment to the Minister of Energy and Mineral Resources Regulation Number 32 (2008): Provision, Utilization and Trading System of Biofuels as Other Fuels (Minister of Energy and Mineral Resources, 2016). In this regulation, the utilization of biofuels (biodiesel, bioethanol and pure vegetable oil) was carried out in stages until 2025 including the transportation, industry and power generation sectors. The mandatory of biodiesel utilization in transportation is set by 20% (B20) for 2016 and 30% (B30) in 2020.

It is well known that biodiesel can be extracted from various resources, such as animal fats, soya bean oil, sunflower oil, palm seed oil, rapeseed oils, and waste cooking oil. The use of biodiesel in conventional diesel engines results in substantial reduction in emission of carbon monoxide, particulates and unburned hydrocarbons, but increases NOx emission (Stepien, *et al.,* 2014; Swaminathan & Sarangan, 2017; Manikumar, *et al*., 2018). The utilization of biodiesel for substituting conventional diesel fuel is an attractive option, but the engine oil degradation increased. Biodiesel was reported has negative impact related to wear metal. However, the utilization of biodiesel was expected to improve durability of engine due to the lower soot formation and the inherent lubricity, compared with diesel (Agarwal & Gupta, 2014).

The presence of B20 as fuel blend will decrease the viscosity and TBN, while oppositely increase the acidity of the engine oil, thus reduce the lifetime of lubricant (Gulzar, *et al*., 2016; Levent, *et al*., 2009). The degradation of lubricant quality is strongly influenced by the type of base oil, lube oil additives components, biodiesel portion, engine design and its operating conditions of the engine (Stepien, *et al*., 2014). In internal-combustion engine operation, dilution of engine oil with biodiesels will change the oil properties, and negatively affect the lubricity performance of engine oil leads to increased surface degradation, as premature wear (Molina, *et al*., 2020). The presence of the bio-components in the fuel significantly impacts the lubricants degradation. The oxidation of lubricants causes the lubricants thicken, to form acids result in lower lubrication qualities. This phenomenon shortens the engine life by creation deposits on engine pistons, in combustion chambers and on valves, sticking rings and provoking the bore polishing (Stepien, *et al*., 2014). Viscosity of engine oil fall to half of the initial value, excessive wear, TBN decrease and TAN increase occurred with biodiesel utilization. It is also found that the acidity of used lubricant in biodiesel fuel engine is higher than diesel fuel. Meanwhile, the TBN values were dramatically decreased when utilized biodiesel (Levent,*et al*., 2009). The mixture of biodiesel results in a faster reduction of the TBN, thus accelerating the deterioration of engine oil (Shimokoji & Okuyama, 2009). Therefore, the use of biodiesel fuel blends will degrade the performance of lubricant and affect the oil drain interval requirements (Thornton, *et al*., 2009). The biodiesel dilution in engine oil was a part of which is attributed to oil related failures of engines (Stepien, *et al*., 2014). The engine oil dilution by methyl esters negatively affects the lubricity performance of engine oil (Molina, *et al*., 2018). TBN can decrease significantly with oil age (Thornton, *et al*., 2009). Contrary, several studies reported that there was no significant differences of viscosities, TBN, and TAN between fresh and used lubricants were observed (He, *et al*., 2011).

The degradation of lubricants depends on operation conditions of the engine, oil performance grade, engine type and its service, thus the engine oil life span is until now not well understood. The incompatibility problems between the lubricants and the biofuels additives should be further observed (Stepien, *et al*., 2014).

In this research, the changes in lubricants properties during the use of B20 were investigated. Two type of vehicles engines were used, namely heavy duty and light duty diesel engines. The road test was carried out until 40,000 km, while the lubricant was drained and analysed only for 10,000 km of distances. The laboratory test was conducted to observe both fresh and used lubricants.

METHODOLOGY

Experimental Set up

The study was conducted by preparation of two types of diesel engine vehicles, fuels, lubricants, and road test. Two types of diesel engines were used, namely heavy duty and light duty diesel engine vehicles. Figure 1 illustrate the schematic diagram of the experimental set up. The road test was carried out until 40,000 km to observe the performances of diesel engines fuelled by biodiesel. The lubricant was changed, drained, and analysed for 10,000 km of distances. The fresh lubricant was used in every 10,000 km of drain interval. The laboratory test was conducted to observe both fresh and used lubricants.

Fuel Properties

In this work, the fuels were directly derived from the producer, which are PT Pertamina (Persero) for diesel fuel (B0) and biodiesel producer who are the members of Indonesian Biofuel Producers Association for the biodiesel (B100). The fuels properties (Table 1) namely B0, B100, and mixed fuel (B20), were analysed using recognized standard test methods according to fuel specification as specified in Decree of Director General of Directorate of Oil and Gas Number 28.K/10/DJM.T/2016 (MEMR, 2016) and Decree of the Director General of Directorate General of New Renewable Energy and Energy Conservation Number 189 K/10/DJE/2019 (Minister of Energy and Mineral Resources, 2019).

Lubricant Properties

The lubricant properties were analyzed both fresh and used oil to observe the oil degradation during utilized (Table 2). The physical and chemical properties of lubricants were including kinematic viscosity at 40^{o}C and 100^{o}C (ASTM D445-17a, 2017), flash point (ASTM D92-11, 2011), water content (ASTM. D6304-07, 2007), TBN (ASTM. D2896-15, 2015), and TAN (ASTM.D664-17, 2017). The properties of lubricants meet the requirements of Indonesian National Standard SNI 7069-5:2021, among them are the specification of SAE 5W30 API CF for light-duty diesel engine, and SAE 15W40 JASO DH-1 for heavy-duty diesel (SNI-7069-5, 2021).

RESULTS AND DISCUSSION

The performances of lubricants were influenced by the fuel being used. The physical and chemical properties of lubricants change during services. Generally, the implementation of biodiesel in diesel engine vehicles will negatively affect the lubricity performance of lubricant result in surface degradation (Molina, *et al.*, 2020).

Used Lubricant Properties

Table 3 and Table 4 present the properties of used lubricants compare to the fresh one during services in light- and heavy-duty diesel engine vehicles. The results show that the lubricant properties were changed. These phenomena were indicated by the change of some critical properties, i.e., kinematic viscosity, flash point, water content, TAN, TBN, insoluble content, carbon residue, and metals content.

Physical properties of the used engine oil

The results show that the kinematic viscosities and flash points of used oil were slightly decreased. On the other hand, the fuel diluent increased (Table 3, Table 4 and Figure 2). The curves indicate the change of lubricants properties in every 10,000 km of

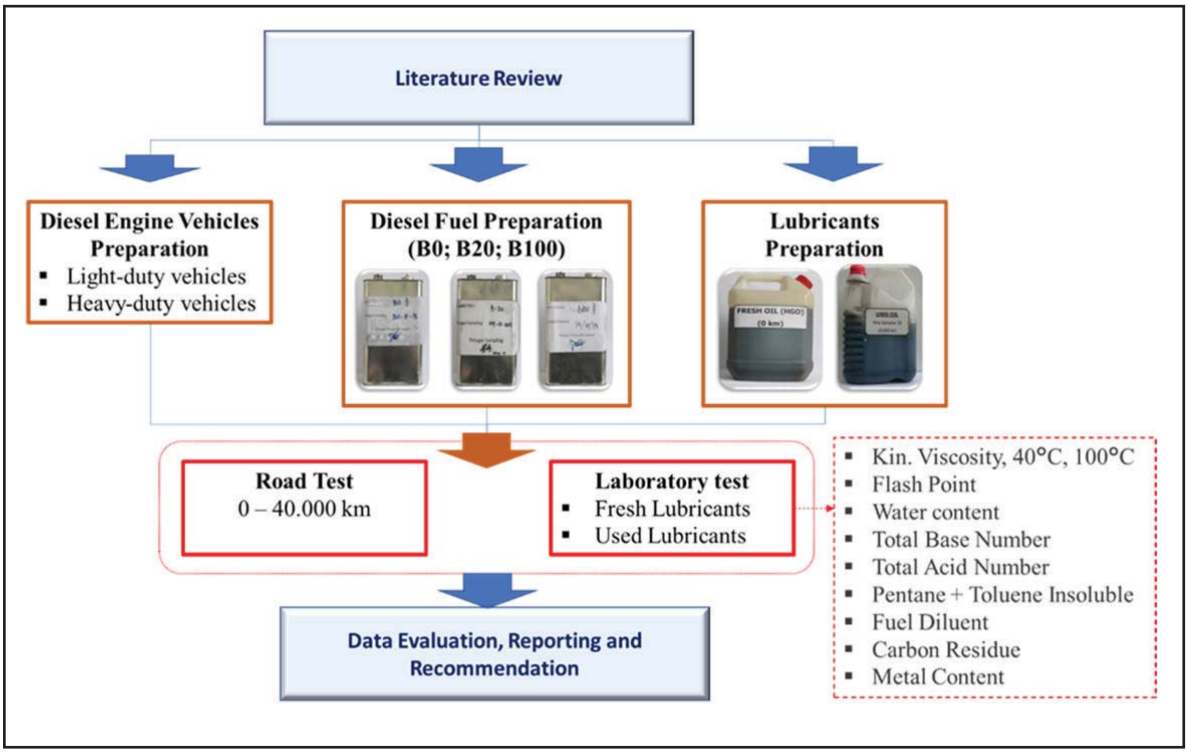

Figure 1
Methodology of Research.

Table 1
Fuel properties

No.	Properties	Unit	Results			Methods
			B-0*	B-100**	B-20*	
1	Cetane number		48.4	62.5	50.1	D 613
2	Cetane index		45.26	-	46.88	D 4737
3	Density @15^{o}C	kg/m^3	825.7	874.7	857.1	D 1298/D 4052
4	Viscosity @40^{o}C	mm^2/s	2.93	4.49	3.22	D 445
5	Sulphur contents	% m/m	0.108	0.002	0.0901	D 2622
6	Distillation: T90	^{o}C	349	354	347	D 86
7	Flash Point	^{o}C	59	161	63	D 93
8	Pour point	^{o}C	-6		-3	D 97
9	Cloud point	^{o}C		16		ASTM D 2500
10	Phosphor	mg/kg		0.013		AOCS Ca 12-55
11	Carbon residue	% m/m	Nil	Nil	nil	D 4530
12	Water contents	mg/kg	68.69	Nil	187.22	D 6304
13	Biological Growth	-	Nil	-	Nil	
14	FAME	% v/v	Nil	-	20.4	D7806
15	Methanol	% v/v	Nil	-	Nil	D 4815
16	Copper strip corrosion	Merit	1a	1a	1a	D 130
17	Ash contents	% m/m	0.003	-	0.003	D 482
18	Sulphated ash contents	% mass	0	0	-	ASTM D 874
19	Sediment contents	% m/m	Nil	nil	Nil	D 473
20	Strong acid number	mg KOH/g	0	0	0	D 664
21	Total acid number	mg KOH/g	0.04	0.39	0.04	D 664
22	Free glycerol	% mass	-	0.0135	-	AOCS Ca 14-56 ASTM D 6584
23	Total glycerol	% mass	-	0.1638	-	AOCS Ca 14-56 ASTM D 6584
24	Methyl- Esther contents	% mass	-	99.67	-	SNI 7182:2012
25	Iod number	% mass	-	87.63	-	AOCS Cd 1-25
26	Oxidation stability, induction periods rancimat method, or Induction periods petro-oxi method	minutes	-	1410	-	EN 15751 ASTM D 7545
27	Monoglyceride content	%m	-	0.37	-	
28	Visual appearances	-	Clear – bright			
29	Color	No. ASTM	1.5	1.5	1.5	D 1500
30	Lubricity (*HFRR wear scar* dia. @60°C)	micron	289	-	265	D 6079
31	Oxidation stability	minutes	>3960	-	>3960	EN 15751
32	Metal contents:	ppm				AAS
	Zn		0	0	0	
	Pb		0	0	0	
	Na		0.5	0.9	2.1	
	K		1.5	1.5	2.4	
	Ca		4.4	0.3	0.2	
	Mg		0.2	0	0	
	Cu		0	0	0	
	Ba		0	0.2	0.2	
	P		0.7	0,2	0,2	

* Decree of Director General of Directorate of Oil and Gas Number 28.K/10/DJM.T/2016 (MEMR, 2016)

** Decree of the Director General of Directorate General of New Renewable Energy and Energy Conservation Number 189K/10/DJE/2019 (MEMR, 2019)

Table 2
The fresh lubricant properties for light- and heavy-diesel engine

No	Properties	Results			Methods
		Unit	Light-duty	Heavy-duty	
1	Kinematic Viscosity, 40°C	cSt	54.71	102.9	ASTM D-445
2	Kinematic Viscosity, 100°C	cSt	9.686	13.47	ASTM D-445
3	Flash Point	°C	236	236	ASTM D-92
4	Water content	mg/kg, %	218.45	241.34	ASTM D-6304
5	Total Base Number	mg-KOH/g	11.94	12.84	ASTM D-2896
6	Total Acid Number	mg-KOH/g	2.38	2.55	ASTM D-664
7	Pentane + Toluene Insoluble	%-wt	0	0	Centrifuge
8	Fuel Diluent	%	0	0	FP as Indicator
9	Carbon Residue	% m/m	0.00024	0.00015	ASTM D-189
10	Metal Content:				
	a. Zn	ppm	1045.8	1447.3	ASTM D-4628
	b. Pb		0	0	AAS
	c. Na		10.5	10.2	
	d. K		7.2	3.1	
	e. Ca		2897.7	2856.4	
	f. Mg		16.4	28.4	
	g. Cu		10.4	10.4	
	h. Ba		574	443.4	

*Laboratory test results

distance and the lubricant was replaced with the fresh one after being drained. In this work, the biodiesel dilutions were less than 2% both in light- and heavy-duty diesel engines. The kinematic viscosities of 4 samples of used lubricants in light-duty diesel engine were decreased in the ranges of 0.58 - 7.5%, while in heavy-duty diesel engines were 4.66-16.04% from the initial values. The final values of kinematic viscosities for light-duty diesel engine were slightly below the ranges of specifications (SNI-7069-5, 2021), for the third and fourth sample, so the performances of lubricant were still acceptable. The similar result also found for heavy-duty diesel engine, where the kinematic viscosities of used lubricants were slightly lower than the specifications as mention in the SNI-7069-5 (2021).

The dilution of biodiesel in engine oil result in lower flash point and in the same time decrease the viscosity. The boiling point of biodiesel is higher than mineral diesel and this fuel interacts with the lubricant via fuel dilution (Agarwal & Gupta, 2014). In the long-term effects, the dilution of biodiesel on engine lubricants could affect the engine efficiency, reduce the fuel economy, and leading to higher emission of greenhouse gas (Hamdan, *et al.*, 2017). The dilution level of biodiesel in lubricant in the ranges of 4-8% indicating there were no observed impacts on performance of the engine or the emission control systems (Thornton, *et al.*, 2009).

Acidity of the used engine oil

Variation of the TAN in used lubricants were the function of time. The results show that the TANs were increased, while the TBN decreased (Figure 3). The TBN values were decreased with the increasing engine operation time, while the acid number increased. The increasing of TANs could be attributed to poor oxidation stability of biodiesel which was gradually diluted in engine oil. The diluted biodiesel induces the formation of oxidative products which is promoting a relatively faster increase the acidity (Stepien, *et al.*, 2014). The acid promotes the formation and progressive accumulation of insoluble sludge (Table 3 and Table 4). The acids can

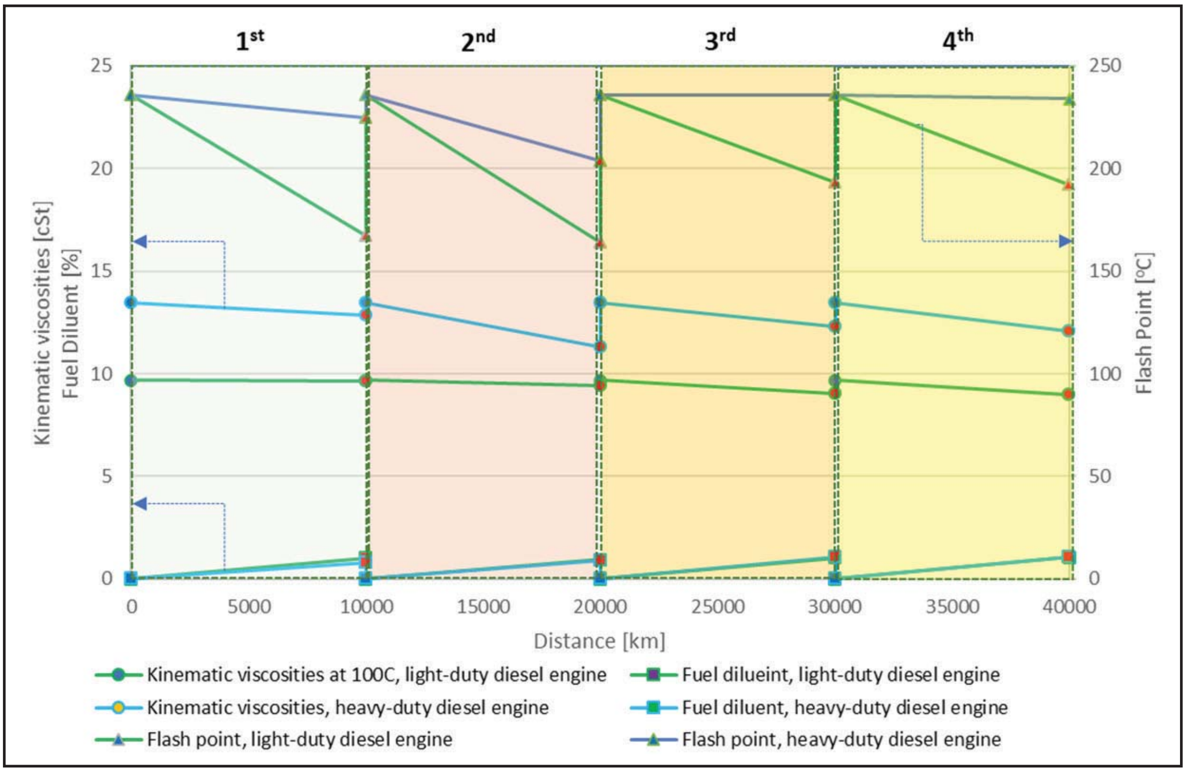

Figure 2
The changes of kinematic viscosities, flash points, and fuel diluents.

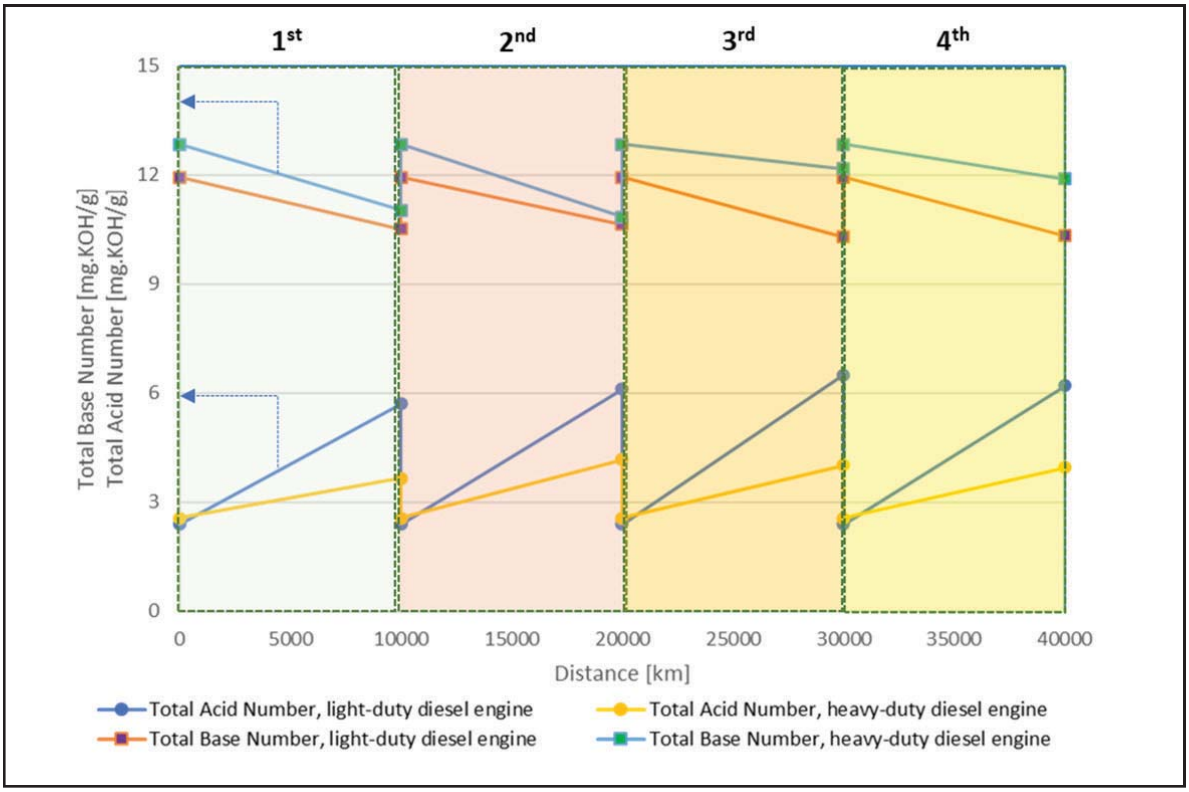

Figure 3
The changes of total acid number and total base number.

be reduced through neutralization reactions with the detergent; thus, the base number fall as the detergent in engine oil additive is neutralized and consumed by heat and the nitric acid. Therefore, maintaining the base number is a crucial in limiting the formation of sludge (Shimokoji & Okuyama, 2009).

In this work, the decreasing of TBNs were less than 14% in light-duty diesel engine and fewer than 16% in heavy-duty diesel engine fuelled by B20. Meanwhile, the acidity of used engine oil was increased until 173% for light-duty diesel engine and 63% heavy-duty diesel engine compare to the initial values. The decrease of TBNs indicate that the base in lubricants neutralize the acids that were formed during services. Until the end of operation, the TBNs were still meet the minimum value as required in the specifications (SNI-7069-5, 2021), so the performances of lubricant were still acceptable.

Metal contents

Metal contents in used lubricants derived from additives (i.e., zinc, calcium), and wear (i.e., lead, copper). The results show that the metal additives decreased while wear metal increased (Figure 4). According to this study, the increasing of wear metal (copper) in the used lubricants were less than 23% in light-duty diesel engine and lower than 26% in heavy-duty diesel engine fuelled by B20. Meanwhile, the lead contents of used engine oil were increased to 3.2 ppm in heavy-duty diesel engine and was not detected in light-duty diesel engine.

The increasing of wear metals mostly derived from bearings which were leached due to biodiesel fuel in the engine oil (Stepien, *et al.*, 2014). This phenomenon was happened because the dilution of biodiesels can reduce the wear protection performance and the viscosity of the engine oil even at small contaminating amounts (Agarwal & Gupta, 2014). The fuel dilution will increase the friction force value, result in the reduction of load carrying capacity of the lubricant. This phenomenon will potentially induce significant wear (Hamdan, *et al.*, 2018). He, *et al.* (2011) found that no significant differences of wear metal between fresh and used engine oil were observed.

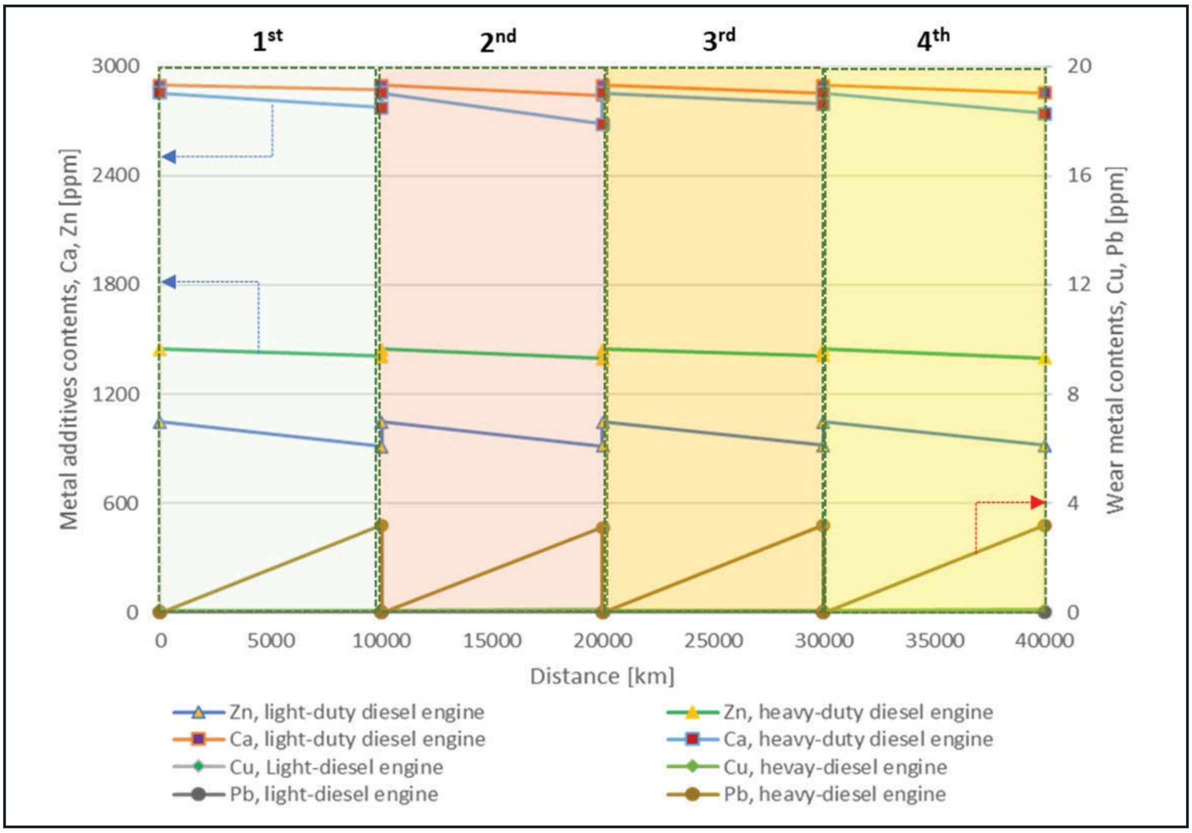

Figure 4
Metal contents of used engine oil.

Table 3
Lubricant properties during service in light-duty diesel engine vehicle

No	Properties	Unit	Value at X Km*					Methods
			Fresh 0	10.000	20.000	30.000	40.000	
				1st	2nd	3rd	4th	
1	Kinematic Viscosity, 40°C	cSt	54.71	53.53	53.45	52.89	52.75	ASTM D-445
2	Kinematic Viscosity, 100°C	cSt	9.686	9.63	9.45	9.06	8.96	ASTM D-445
3	Flash Point	°C	236	167	164	193	192	ASTM D-92
4	Water content	mg/kg, %	218.45	270.37	201.5	230.6	229.5	ASTM D-6304
5	Total Base Number	mg-KOH/g	11.94	10.51	10.63	10.29	10.32	ASTM D-2896
6	Total Acid Number	mg-KOH/g	2.38	5.7	6.1	6.5	6.2	ASTM D-664
7	Pentane + Toluene Insoluble	%-wt	0	7.8+5.4	4.4+2.6	7.5+4.9	4.5+3.9	Centrifuge
8	Fuel Diluent	%	0	1.04	0.96	1.03	1.05	FP as Indicator
9	Carbon Residue	% m/m	0.0002	0.001	0.001	0.001	0.001	ASTM D-189
10	Metal Content:							
	a. Zn	ppm	1045.8	910.3	914.2	916.5	918.5	ASTM D-4628
	b. Pb		0	0	0	0	0	AAS
	c. Na		10.5	10.2	10.9	9.9	10.1	
	d. K		7.2	7.6	6.5	8.1	7	
	e. Ca		2897.7	2873.7	2843.9	2856.8	2856.5	
	f. Mg		16.4	16.1	16.2	16.4	16.6	
	g. Cu		10.4	12.8	9.5	10.5	10.3	
	h. Ba		574	560	571	578	581	

*Laboratory test results

Table 4
Lubricant properties during service in heavy-duty diesel engine vehicle

No	Properties	Unit	Value at X km *					Methods
			Fresh 0	10	20	30	40	
				1st	2nd	3rd	4th	
1	Kinematic Viscosity, 40°C	cSt	102.9	99.5	91.74	90.68	90.56	ASTM D-445
2	Kinematic Viscosity, 100°C	cSt	13.47	12.84	11.31	12.29	12.09	ASTM D-445
3	Flash Point	°C	236	225	204	236	234	ASTM D-92
4	Water content	mg/kg, %	241.34	335.8	333.4	334.4	335	ASTM D-6304
5	Total Base Number	mgKOH/g	12.84	11.02	10.84	12.16	11.88	ASTM D-2896
6	Total Acid Number	mgKOH/g	2.55	3.65	4.16	4.01	3.95	ASTM D-664
7	Pentane + Toluene Insoluble	%-wt	0	8.5+6.7	7.9+5.6	8.2+5.8	8.0+4.9	Centrifuge
8	Fuel Diluent	%	0	0.82	0.89	1.06	1.08	FP as Indicator
9	Carbon Residue	% m/m	0.00015	0.002	0.002	0.002	0.002	ASTM D-189
10	Metal Content:							
	a. Zn	ppm	1447.3	1406.4	1395.7	1411.7	1398.6	ASTM D-4628
	b. Pb		0	3.2	3.1	3.2	3.2	AAS
	c. Na		10.2	11.1	9.8	9.9	10	
	d. K		3.1	3.6	2.5	3	3.1	
	e. Ca		2856.4	2775.4	2685.6	2794.8	2743.6	
	f. Mg		28.4	27.8	30.3	29.6	31.6	
	g. Cu		10.4	12.9	13.1	12.9	13	
	h. Ba		443.4	459.5	460	458.6	460.4	

*Laboratory test results

CONCLUSIONS

Mostly, the implementation of biodiesel in diesel engine vehicles will negatively affect the lubricity performance of lubricant result in surface degradation. However, the degradation levels are highly depending on operation conditions of the engine, oil performance grade, engine type and its service. This work, evidence that the lubricant properties were gradually changed as indicated by the change of some critical properties, i.e., kinematic viscosity, flash point, water content, TAN, TBN, insoluble content, and metals content. In this work, the biodiesel dilution is less than 2%, result in the lower kinematic viscosities and flash points of used oil. The dilution of biodiesel fuel increases the oxidation tendency and generates a relatively faster acid formation. The acid numbers of engine oil were increased, while the base number decreased. the decreasing of base number was about 14% in light-duty diesel engine and only 5% in heavy-duty diesel engine fuelled by B20. Meanwhile, the acidity of used engine oil was increased 173% for light-duty diesel engine and 63% heavy-duty diesel engine compare to the initial values. The metal additives decreased while wear metal increased. The increasing of wear metal was less than 23% in light-duty diesel engine and below 26% in heavy-duty diesel engine fuelled by B20. Meanwhile, the lead contents of used engine oil were increased to 3.2 ppm in heavy-duty diesel engine and was not detected in light-duty diesel engine.

After all, this work found that the lubricants exhibit good performances in the light- and heavy-duty diesel engines fuelled by B20. The changes of some critical properties were still in the acceptable values regarding to the specification as required in the SNI-7069-5 (2021).

ACKNOWLEDGEMENT

The authors would like to thank to Ministry of Energy and Mineral Resources for financial assistance and PPPTMGB "LEMIGAS" for supporting data and documentation.

GLOSSARY OF TERMS

Symbol	Definition	Unit
TBN	Total base number	mg.KOH/gr
TAN	Total acid number	mg.KOH/gr
MEMR	Ministry of Energy and Mineral Resources	
NOx	Nitrogen Oxide	
ASTM	American Standard for Testing and Materials	
SAE	Society of Automotive Engineering	
JASO	Japanese Automotive Standards Organization	
FAME	Fatty Acid Methyl Ester	
FP	Flash point	^{o}C
AAS	Atomic absorption spectroscopy	
SNI	Standar Nasional Indonesia	

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