VALUATING THE IMPACT OF BIODIESEL B10, B20 ON LUBRICATING OIL IN A COMMONRAIL DIESEL ENGINE

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Abstract - Biodiesel typically has a higher boiling point, viscosity, density, and surface tension compared to traditional diesel. This can result in larger fuel droplets and potentially increased penetration into the engine crankcase. This article presents experimental findings on the impact of using biodiesel blends B10 and B20 (with B100 made from palm oil) on key lubricating oil properties in a D4CB 2.5TCI-A diesel engine equipped with a CommonRail fuel injection system installed in a Hyundai Starex vehicle. The evaluation is based on comparing lubricating oil properties when using different fuels: diesel (B0), biodiesel B10, and biodiesel B20 over a 3000 km driving cycle. Results indicate that the effects of B10 and B20 on lubricating oil properties are similar to those of conventional diesel B0.

Key words - Biodiesel B10; Biodiesel B20; Lubricating oil properties; CommonRail diesel engine

1. Introduction

When transitioning to the use of biodiesel fuel, it is essential to comprehensively evaluate the impact of biodiesel on the engine. This includes assessing its effects on fuel injection processes, combustion emissions levels, material compatibility with biodiesel, engine performance parameters [1], [2], [3], [4], as well as its influence on the quality of engine lubricating oil [5], [6].

Biodiesel's higher boiling point, viscosity, density, and surface tension compared to traditional diesel fuel tend to produce larger fuel droplets during injection. These droplets can adhere in liquid form to the cylinder walls and seep into the crankcase, particularly after passing through the piston rings. Once in the crankcase, biodiesel may degrade into organic acids and interact with metals to initiate polymerization processes, leading to the formation of sludge deposits. Furthermore, due to its higher boiling point, biodiesel reduces the amount of fuel vapor that can evaporate from the crankcase, which is vented by the ventilation system. The dilution of lubricating oil by fuel increases the risk of wear, corrosion, deposit formation, and deterioration of lubricant quality. Additionally, by-products of biodiesel oxidation can adversely affect bearing materials such as lead-based materials [6], [7], [8].

In Vietnam, numerous studies have been conducted on the production and utilization of biodiesel for diesel engines across various technology levels and sectors including marine vessels, agricultural machinery, power generators, military vehicles, road vehicles, and others [1], [2]. Within the framework of a national-level project [1], biodiesel (B100) is produced from the waste residue of the crude palm oil refining process into cooking oil, meeting current Vietnamese standards. This B100 type does not compete with food, instead utilizing waste from the cooking oil production process. Detailed analysis results of the properties of traditional petroleum diesel (referred to as B0), B10 (containing 10% biodiesel), and B20 (containing 20% biodiesel) are presented in Table 1 [1], [2], [9]. The properties of B10 and B20 are compared and evaluated based on Vietnamese standards QCVN 01:2009/BKHCN, TCVN 5689:2005, and ASTM D 7467/09 (American standard for biodiesel fuel blends ranging from 6 to 20%). The evaluation of fuel properties indicates that B10 and B20 produced and blended according to the procedures outlined in the national-level project fall within the permissible limits of QCVN 1:2009/BKHCN, TCVN 5689:2005, and ASTM D 7467/09, making them suitable for use as alternative fuels for diesel engines.

The evaluation of biodiesel's impact on lubricating oil is commonly conducted through experimental studies [5], [6], [7], [8]. In previous research conducted by the authors [5], the effects of using B10 and B20 blends with properties outlined in Table 1 were investigated on a B2 diesel engine. This engine had a compression ratio of 15, no turbocharging, and utilized a conventional mechanical fuel injection system with a start injection pressure of 21 MPa [10]. The analysis involved examining oil samples taken over an oil change cycle of 500 operating hours. The results suggested that there may be no need to adjust the type and interval of lubricating oil when transitioning to B10 or B20 blends.

In the study [6], two types of engine lubricants were utilized: a mineral oil-based lubricant and a synthetic oil. These lubricants were mixed with three types of FAME sourced from Soy methyl ester (SME), Rapeseed methyl ester (RME), and Palm methyl ester (PME) in blend ratios of B5 (5% FAME), B7 (7% FAME), and B20 (20% FAME). The High Temperature Corrosion Bench Test (HTCBT) was employed to evaluate the corrosion of metals such as copper and lead, with the lubricants heated to 135°C for 168 hours with air blown through. The study revealed several key trends: SME caused significant copper corrosion even at a 1% blend, with corrosion levels increasing as SME content rose from 1% to 5%; Lead corrosion increased exponentially with FAME content, with 5% SME resulting in lead levels exceeding 1000 ppm; SME significantly lowered the onset oxidation temperature of the lubricant, indicating poorer oxidative stability compared to PME and RME. The authors concluded that biodiesel, particularly from sources like soybean and rapeseed, can increase corrosion and decrease the oxidative stability of lubricants, highlighting the need for new lubricant technologies to mitigate these negative effects.

In the work [7], commercial SAE 15W-40 API CF-4 engine oil was blended with three types of FAME: Palm methyl ester (PME), Jatropha methyl ester (JME), and waste cooking oil methyl ester (WME) at concentrations of 5%, 10%, 15%, and 20% by weight. The effects of biodiesel contamination on oil properties were assessed using various methods, including ASTM standards for viscosity and Total Acid Number (TAN) and wear performance tests. The results indicated that biodiesel contamination generally decreased the viscosity of engine oil, particularly with palm and jatropha biodiesel, but improved lubricity, enhancing wear protection. Waste cooking oil had the least impact on viscosity but significantly improved the viscosity index. The authors concluded that while biodiesel contamination reduces engine oil viscosity, raising concerns about oil drain intervals, it also improves lubricity, suggesting the need for further development of engine oils to accommodate biodiesel contamination while maintaining performance.

In the study [8], the authors investigated the impact of biodiesel on engine performance, exhaust emissions, and lubricating oil durability. They used a single-cylinder, four-stroke, air-cooled marine diesel engine to compare the effects of commercial diesel fuel and 100% rapeseed methyl ester (RME). Durability tests over 150 hours revealed that RME decreased lubricating oil viscosity and base number more than diesel, leading to higher iron and other wear metal concentrations in the oil. The authors confirmed that while biodiesel can reduce some harmful emissions, it can also compromise the lubricating properties of engine oils, indicating a need for further research into mitigating these adverse effects.

The D4CB 2.5 TCI-A diesel engine installed in the Hyundai Starex vehicle features a compression ratio of 17.6. It utilizes a CommonRail (CR) fuel injection system with a maximum injection pressure of 1600 bar, alongside variable geometry turbocharging and an exhaust gas recirculation system. This engine complies with Euro 3 emission standards. Its combustion and mixture formation technology closely resemble that of many other engines and vehicles currently available on the market, [2].

Table 1. *Properties of fuel samples B0, B10, B20, [1], [2], [4], [9]*

No	Property	Test Methods	Unit	Results			Range (TCVN 5689:2005)	Range (QCVN 1: 2009/BKHCN)	Range (ASTM D 7467/09)
				B0	B10	B20			
1	Sulfur Content	TCVN 6701:2000	mg/kg	0.038	0.0315	0.0312	max; 0,05	-	max; 0.05
2	Distillation Temperature, °C, 90% vol recovered, max	TCVN 2698:2002	ºC	332	335	338	360	-	max; 343
3	Flash Point, °C, min	TCVN 6608:2000	ºC	60	64	67	min; 55	-	min; 52
4	Viscosity, mm2 /s at 40°C	TCVN 3171:2003	mm^2/s	3.14	3.25	3.38	1.9÷4.5	1.9÷6.0	1.9÷4.1
5	Ramsbottom Carbon Residue on 10% bottoms, mass %, max	TCVN 6324:1997	% weight	0.06	0.08	0.11	max; 0.3	-	max; 0.35
6	Cloud Point, °C, max	ASTM D 2500	ºC	+3	+4	+3	Report	-	Report
7	Ash Content, mass%, max	TCVN 2690:1995	% weight	0.002	0.003	0.004	max; 0.01	max; 0.020	max; 0.01
8	Water and Sediment, volume%, max	ASTM D 2709	% volume	0.005	0.005	0.005	max; 0.02	max; 0.050	max; 0.05
9	Oxidation Stability, hours, min	EN 14112	hour	18.24	77.27	26.25	min; 6	min; 6	min; 6
10	Copper Corrosion, 3 h at 50°C, max	TCVN 2694:2000	No	1	1a	1a	max; 1a	-	max; 1a
11	Cetane Number, min	TCVN 7630		49	56.3	56.7	min; 40		min; 40
12	Density at 15°C	TCVN 6594:2000	kg/l	0.8369	0.8409	0.8448	820÷860	-	-
13	Acid Number	ASTM D 664	mg KOH/g	0.023	0.034	0.042	-	max; 0.50	max; 0.30
14	Low heating value	ASTM D 240	MJ/kg	45.19	43.86	43.11	-		-

This article presents experimental findings on how B10 and B20 fuels impact the lubricating oil properties of the D4CB 2.5 TCI-A diesel engine. The evaluation compares oil sample analyses across three fuel types: diesel (B0), biodiesel B10, and biodiesel B20, with each corresponding to a vehicle operating distance of 3000 km. The experiment, which assesses the impact of biodiesel on lubricating oil, was conducted directly on the engine during operation, offering the advantage of time and cost savings while maintaining acceptable reliability. The subsequent sections of this paper will delve into the Testing methodology, outlining the research approach. The Results and Discussion section will present the analysis results of lubricating oil samples and evaluate the extent of changes in their properties, comparing them against established standards. The Conclusion section will assess the impact of B10 and B20 on lubricating oil in the case study, recommend the lubricating oil change interval based on the study findings, acknowledge the limitations of this research, and propose potential directions for future studies.

2. Testing methodology

- Research methodology: The study employs a comparative control approach to analyze variations in the primary properties of lubricating oil when the engine operates on three types of fuels: B10, B20, and B0 (pure diesel). The comparison is conducted over the same mileage of 3000 km, chosen to align with the typical oil change interval of 5000 km recommended for the vehicle. The experiments are carried out on a single Hyundai Starex vehicle throughout the testing process to ensure consistency in technical conditions and operational parameters.

- Type of lubricating oil used: Vecton 15W-40/Castron. During vehicle operation, any depleted lubricating oil in the engine is replenished with fresh lubricating oil of the same brand and type.

- Sampling timing and method: Lubricating oil samples are collected twice at 1500 km and 3000 km intervals. The sampling process for the lubricating oil involves the following steps: Start the engine and run it until reachingnormal operating temperature; Turn off the engine and collect the lubricating oil sample; Replenish the depleted lubricating oil with an equivalent amount of fresh lubricating oil. Sampling location: The lubricating oil is sampled from the front of the oil filter housing to ensure that the properties of the lubricating oil are not affected and to facilitate easy handling.

- The properties to be analyzed: TCVN 8939-15:2014 is used to assess the characteristics of the new lubricating oil samples. As there are no specific technical standards for in-used lubricating oil, the study relies on the "Foundation standard" provided by the PetroVietnam Oil Processing and Trading Company (PVPDC) pertaining to "Testing and Evaluating Used Engine Oils" [11]. Based on the research objectives and conditions, the parameters requiring analysis for both new and used lubricating oil samples are determined as listed in Table 2. All oil samples are analyzed at the Petroleum Products Testing Laboratory of the Center for Standards Measurement and Quality 1 (Quatest 1) using standard measuring equipment, [2].

The lubricating oil type and the sampling process are illustrated in Figure 1, while Figure 2 displays images of lubricating oil samples collected at 0 km (new oil), 1500 km, and 3000 km, corresponding to B0, B10, and B20 usage conditions, respectively.

Figure 1. *Type of lubricating oil and test vehicle*

Samples	At 0 km	At 1500 km	At 3000 km
Lubricating oil sample (B0)			
Lubricating oil sample (B10)			
Lubricating oil sample (B20)			

Figure 2. *Samples of lubricating oil collected corresponding to the types of fuels and sampling times*

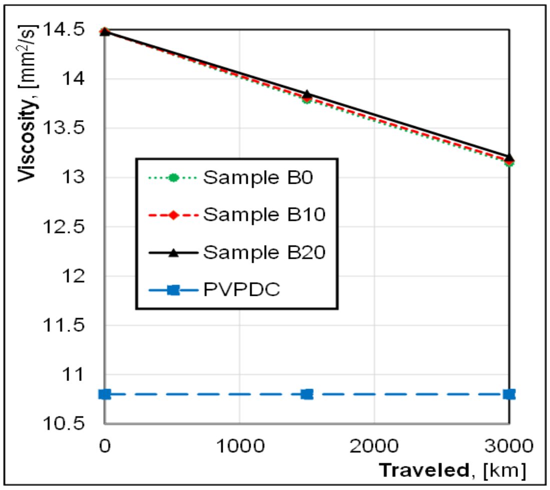
Table 2. *Properties and test methods for lubricating oil samples*

No	Property	Test methods	Unit	"Foundation standard", [11]	
				Acceptance Criteria	Dangerous Value
1	Viscosity at 100°C	TCVN 3171:2011	mm^2/s (cSt)	Within the SAE Classification Limits	Decreased by 25% or increased by 35% from the original value
2	Total Acid Number (TAN)	TCVN 2595:2008	mgKOH/g	-	-
3	Total Base Number (TBN)	ASTM D 2896-01	mgKOH/g	50% of the original value	< 2
4	Closed Cup Flash Point Temperature	TCVN 2693:2007	^{0}C	Decrease by 25% compared to the original value	150 ^{0}C (crankcase explosion)
5	Insoluble Residue in Pentane	ASTM D 4055-04 (2013)	% weight	< 5	> 6
6	Insoluble Residue in Toluene	ASTM D 4055-04 (2013)	% weight	< 2	> 3
7	Water Content	TCVN 2692:2007	% volume	0.02	0.05 or the water separates

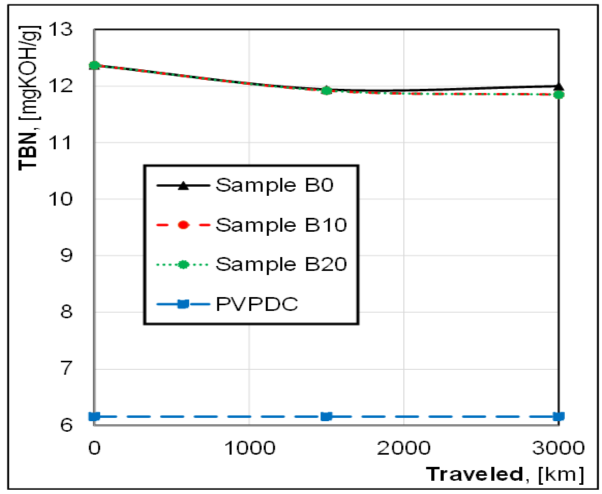
3. Results and discussion

The results of the analysis and the changes in the key properties of the lubricating oil when using B0, B10, and B20 fuels are presented in Table 3 and Figure 3. Here are the observations:

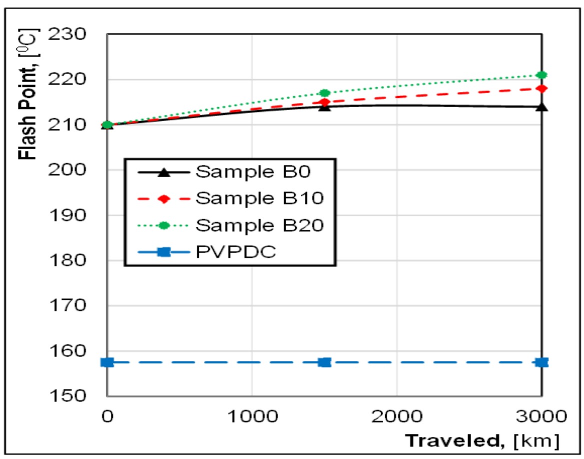
- The kinematic viscosity at 100°C of all samples decreased with mileage with a similar degree of viscosity decrease among the three samples using B0, B10, and B20. At 3000 km, the percentage decrease in kinematic viscosity for engines using B0, B10, and B20 fuels was 9.18%, 9.04%, and 8.77% respectively. According to the evaluation threshold in Table 2, the kinematic viscosity values at 100°C for these samples remained within the permissible limits. The decrease in kinematic viscosity is attributed to the decomposition of polymer compounds in the lubricating oil and the phenomenon of fuel and gas blow-by (containing combustion products) into the crankcase during engine operation.



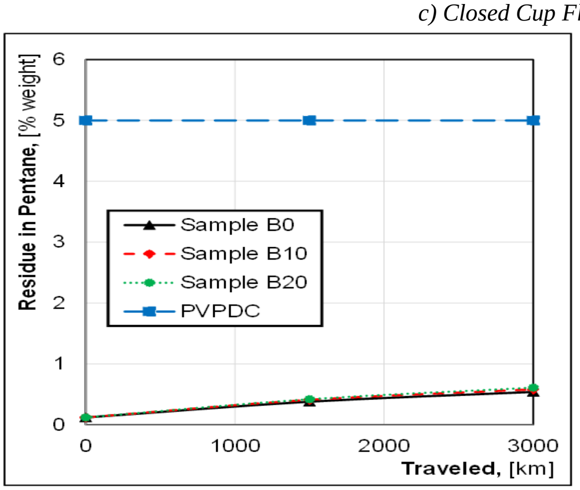
a) Dynamic viscosity at 100°C



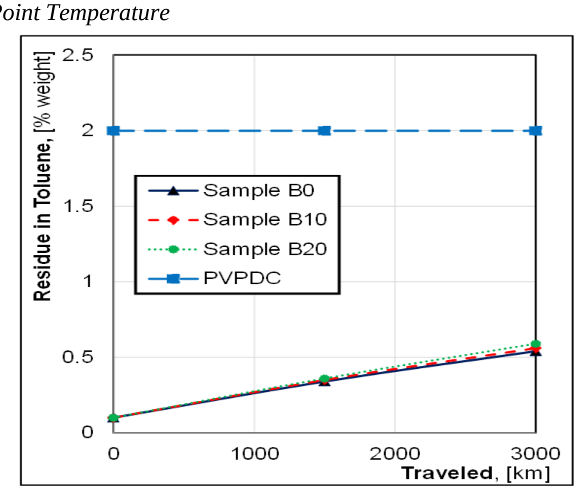
b) Total Base Number (TBN)



c) Closed Cup Flash Point Temperature



d) Residue in Pentane



e) Residue in Toluene

Figure 3. *Degree of changes in properties of lubricating oil when using fuel B0, B10, B20*

Table 3. *Analysis results of lubricating oil samples when using B0, B10, B20*

Property, Units, Degree of change	Test methods	Lubricating oil samples							Range, [10]
		B0			B10		B20		
		0 km	1500 km	3000 km	1500 km	3000 km	1500 km	3000 km	
Dynamic viscosity at 100°C, mm²/s (change, %)	TCVN 3171: 2011	14.48	13.79 (-4.76)	13.15 (-9.18)	13.81 (-4.62)	13.17 (-9.04)	13.85 (-4.35)	13.21 (-8.77)	10.8; min
Total Acid Number (TAN), mgKOH/g (change, %)	TCVN 2595:2008	2.0	2.07 (+3.5)	2,27 (13.5)	2,08 (+4.0)	2,31 (+15.5)	2.11 (5.5)	2.35 (17.5)	-
Total Base Number (TBN), mgKOH/g (change, %)	ASTM D 2896-01	12.37	11.94 (-3.47)	12.0 (-2.99)	11.89 (-3.88)	11.75 (-5.01)	11.92 (-3.63)	11.85 (-4.20)	6.16; min
Closed Cup Flash Point Temperature, ºC (change, %)	TCVN 2693:2007	210	214 (1.90)	214 (1.90)	215 (2.38)	218 (3.80)	217 (3.33)	221 (5.23)	157.5; min
Insoluble Residue in Pentane, % by weight (change, %)	ASTM D 4055-04 (2013)	0.12	0.38 (216.66)	0.54 (350)	0.41 (241.66)	0.58 (383.33)	0.42 (250)	0.61 (408.33)	5; max
Insoluble Residue in Toluene, % by weight (change, %)	ASTM D 4055-04 (2013)	0.10	0.34 (240)	0.54 (440)	0.35 (250)	0.56 (460)	0.36 (260)	0.59 (490)	2; max
Water Content, % volume	TCVN 2692:2007	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.2; max

- The total base number (TBN) tended to decrease with mileage. At 3000 km, the reduction in TBN was 2.99%, 5.01%, and 4.2% for engines using B0, B10, and B20 respectively. These values remained within the permissible limits according to Table 2. The decrease in TBN is due to combustion products (acidic in nature) entering the passages during engine operation.

- The total acid number (TAN) showed a significant increase at the 3000 km mark with corresponding increases of up to 15.5% and 17.5% when using B10 and B20 fuels while the increase with B0 was only 13.5%. The increase in TAN indicates oxidation or degradation of the lubricating oil which is a concerning issue when using biodiesel in engines.

- The closed cup flash point of the lubricating oil samples tended to increase with mileage with the highest increase at 3000 km reaching 1.9%, 3.8%, and 5.23% when using B0, B10, and B20 respectively. All values exceeded the minimum requirement (157.5°C).

- The insoluble residue in Pentane tended to increase with mileage but remained within the permissible limit (< 5). The insoluble residue in Toluene increased in the lubricating oil samples with mileage but remained within the permissible limit (< 2). The test results also showed that the increase in residue content in lubricating oil when using B10 and B20 fuels did not change significantly compared to the B0 sample at the same analysis time.

- The water content in the lubricating oil when using B0, B10, and B20 fuels was low (< 0.05) compared to the maximum allowable limit of 0.2.

4. Conclusion

The dynamic viscosity of the lubricating oil decreases with increasing mileage, with similar reductions observed for all tested fuels (B0, B10, B20). Despite this decrease, the viscosity values remain within acceptable limits according to the specified standards. A significant increase in TAN is observed at 3000 km, with B10 and B20 fuels showing higher increments compared to B0. This suggests increased oxidation or degradation of the lubricating oil, indicating a potential concern when using biodiesel fuels. The TBN tends to decrease with mileage; however, the reductions observed for B10 and B20 fuels are slightly higher compared to B0, indicating increased acidic combustion products entering the oil. The closed-cup flash point exhibits a slight increase with mileage, with the highest increment observed for B20 at 3000 km. All values remain above the minimum required threshold, indicating satisfactory safety levels. Both insoluble residue percentages in Pentane and Toluene show an increasing trend with mileage, although they remain within permissible limits. The rise in residue levels indicates the potential accumulation of combustion by-products in the lubricating oil. The water content in the lubricating oil remains low (< 0.05%) for all tested fuels, well below the maximum allowable limit of 0.2%. Overall, the analysis reveals that while the use of biodiesel blends (B10, B20) leads to changes in certain properties of the lubricating oil compared to conventional diesel (B0), these changes generally remain within acceptable limits. However, increased oxidation, acidity, and insoluble residue accumulation highlight areas that warrant further attention when considering the impact of biodiesel usage on engine lubrication.

Throughout the 3000 km running period, the pattern of changes in the properties of the lubricating oil is similar when the engine uses the three types of fuel; no significant deviation in the properties of the lubricating oil samples on engines using B10 and B20 fuels compared to the control sample on engines using B0 was observed. With biodiesel B10 and B20 possessing properties as described in Table 1, when used as fuel for the D4CB 2.5 TCI-A diesel engine and similar engines, there may be no need to change the type of lubricating oil and the oil change interval.

Nevertheless, constrained by equipment limitations, this study did not evaluate the fuel's solubility in the lubricating oil, the formation of potent acids in the lubricating oil when utilizing B10 and B20 fuels, or the alteration in metal concentrations (such as lead and copper) within the lubricating oil.

In addition to addressing the aforementioned limitations, future research could explore the following directions: evaluating the impact of B10 and B20 on lubricating oil in diesel engines utilizing modern fuel injection strategies, especially post-injection, to support the operation of exhaust after-treatment systems such as SCR and DPF; assessing the effects of B10 and B20 on the wear of related components such as piston rings, cylinder liners, and engine bearings; and developing additives for lubricating oil to improve its compatibility with biodiesel usage.

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