

Impact of using B100 Biodiesel in Ship Engines

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ABSTRACT

The usability of fuel for ship engines produced from palm oil was investigated as pure biodiesel (B100) and with a 5% blend of petroleum diesel fuel (B5) in a 441 kW main engine and a 177 kW diesel generator. The objectives were to investigate the effects of B100 on the brake specific fuel consumption (BSFC), brake thermal efficiency (η_{tb}), exhaust gas temperature (EGT) and carbon monoxide (CO) content in the exhaust gas and the effect on engine parts, compared with B5. All experiments were undertaken in the Naval Dockyard Department. The main engine and diesel generator were worked at 60 and 40% engine load, respectively. The average values of BSFC for B100 when used with the main engine were higher than for B5 and in the range 16.14- 26.00%, because B100 had a lower heating value and higher density compared with B5. The impact on emissions was based on the average values of CO produced by B100 when used in the main engine at a speed of 800 rpm and was 11.09% higher than for B5. However, at speeds of 1100 and 1400 rpm, B100 produced 4.84% and 27.25% less CO than B5, respectively, because B100 had a higher flash point and oxygen content compared with B5. In addition, corrosion from soot and deposits using B100 should be comparable to those from using B5, if the water content does not exceed 0.05% by weight.

Keywords: biodiesel, ship engine, comparison between B100 and B5, impact on fuel consumption and emissions, effect on engine parts

INTRODUCTION

At present, energy problems are being encountered all over the world, which is making several countries investigate new energy sources in order to replace decreasing supplies of existing ones. Such new sources are known as alternative energy or renewable energy, and biodiesel is one example. Biodiesel is an alternative diesel fuel that can be produced from renewable feedstock, such as vegetable oils, waste frying oils and animal fats (Lu *et al.*, 2008). Biodiesel can be either blended

in any proportion with normal diesel oil to create a biodiesel blend or used in its pure form (B100). It is oxygenated and biodegradable, and can reduce the emission of toxic gases like carbon dioxide (CO₂), volatiles organic compounds (VOCs), unburned hydrocarbons (UHC), carbon monoxide (CO), sulfur oxides (SO_x), polycyclic aromatic hydrocarbons (PAH), nitrated polycyclic aromatic hydrocarbons (n-PAH), and particulate matter (PM). With these advantages, biodiesel as an alternative energy is the subject of much interest.

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A study by the National Institute for Occupational Safety and Health (NIOSH) showed that biodiesel does not harm fish. The University of California has also published a paper describing the effect of biodiesel on plants in a marshland and on the water ecosystem, which found that biodiesels were much less toxic than normal diesel. Biodiesel degrades at the same rate as sugar, which is about four times faster than for petro-diesel. Tests by the University of Idaho found that mixing petro-diesel with biodiesel in certain proportions resulted in a degradation rate that was three times faster than that of petro-diesel. In addition, biodiesel also helped in reducing the water pollution because biodiesels have good combustion efficiency that produces less soot and smoke and takes less time for engine warming. Biodiesels also have less non-complete combustion of fuel, which will dissolve into the water. Regarding the effect of biodiesels on ship engines, biodiesels have a higher cetane number and better lubricating power than normal diesels, which prevent early break down and cracking, as well as increasing the lifespan of the engine, resulting in less maintenance expenditure. The higher cetane number results in complete combustion, better ignition and improves the efficiency of the engine with less smoke produced.

For these reasons, the use of biodiesels in ship engines will be beneficial to the aquatic environment and to the engine itself. No engine modification is required, other than cleansing of the fuel tank and occasional hose replacements. This makes biodiesel more acceptable to engine manufacturers in the USA, Europe and Japan and increases the importance of studies into mixing biodiesel with petro-diesel or even using biodiesel in its pure form (B100) (Wedell, 1999). In Thailand, there is only limited use of biodiesels in water transportation, due to the lack of knowledge about this type of alternative energy and a consequent lack of confidence in its use. Thus, it is important and necessary to undertake studies

on using B100 Biodiesel in ship engines.

The current project to study the use of biodiesels in ship engines was carried out with the cooperation of the Naval Dockyard Department, the Royal Thai Navy and PTT Public Company Limited. To serve the purposes of His Majesty the King of Thailand, this project investigated the effects on the performance, emission and engine parts of using B100 biodiesels in MAN engines (models D2842 LE and D2866 TE) belonging to the Naval Dockyard Department. This project will help to build confidence in and understanding of the use of biodiesel B100, so that it can replace normal diesels in the future and make Thailand more energy stable, as the country can grow its own palm oil and so would not need to worry about any shortage of diesel oil.

MATERIALS AND METHODS

Materials

Biodiesel produced from palm oil in a pure form, as B100 (Naval Dockyard Department, Royal Thai Navy, Thailand) and in a blended form, B5 (PTT Public Company Limited, Thailand) were tested in both a main engine (MAN D2842 LE, Germany) and a diesel generator (MAN D2866 TE, Germany). The fuel properties and engine specifications are summarized in Tables 1 and 2, respectively.

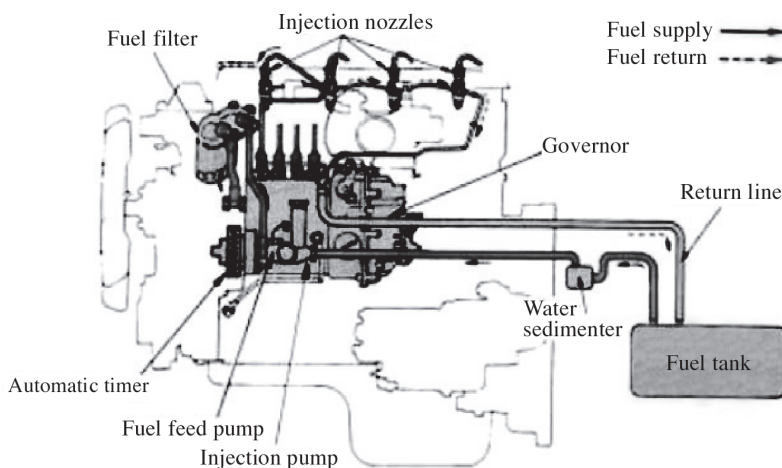
The main parts of an engine are illustrated in Figure 1. The process starts with oil in a fuel tank pumped through a water sedimenter to a fuel filter by the fuel feed pump. Then, oil enters the injection pump, passing through the spill port. The spill port is closed when the pump accommodating space changes position due to the action of the drive cam. The oil is compressed, with the resultant increasing pressure sufficient to overcome the spring pressure of the injection nozzles. At this time, with each power stroke, oil is injected through a nozzle needle as a jet-shaped spray, according to the air compression in the

Table 1 Comparison of physicochemical properties of palm oil biodiesel in pure (B100) and blended (B5) forms and of petro-diesel fuel.

Property	Test method	B100	B5	Petro-diesel
Carbon (wt %)	ASTM D 5291	76.38	85.52	86.09
Hydrogen (wt %)	ASTM D 5291	12.62	13.93	13.91
Nitrogen (wt %)	ASTM D 5291	not available	not available	not available
Oxygen (wt %)	ASTM D 5291	10.87	0.54	not available
Copper strip corrosion (no.)	ASTM D 130	1a	1a	1a
Density at 15.6°C (kg/m ³)	ASTM D 4052	877.9	827.9	827.8
Flash point (°C)	ASTM D 93	154.5	67.0	64.0
Net heating value (MJ/kg)	ASTM D 240	37.21	43.06	43.42
Viscosity at 40°C (cSt)	ASTM D 445	4.863	3.371	3.124
Water content (wt %)	ASTM D 6304	0.1349	0.0110	not available
Water and sediment (vol %)	ASTM D 2709	< 0.025	< 0.025	< 0.025

Table 2 Specifications of main engine and diesel generator.

Model	MAN D2842 LE	MAN D2866 TE
Design	V-form, 90°	In-line vertical
Cycle	4-stroke diesel with turbocharger and intercooler	4-stroke diesel with Turbocharger
Combustion system	Direct injection	Direct injection
Turbocharging	Turbocharger with intercooler	Turbocharger
Number of cylinders	12	6
Bore × Stroke (mm)	128 × 142	128 × 155
Swept volume (cm ³)	21,930	11,967
Compression ratio	15.5:1	15.5:1
Rating (kW/rpm)	441/1800	177/1500

**Figure 1** Mechanism of a diesel engine using a fuel system with an in-line type of injection pump.

combustion chamber, until it is vaporized and mixes with air. Finally, this mixture is combusted (or ignited) and passes out of the combustion chamber in the exhaust stroke. The oil that is not combusted is sent back to the fuel tank through the return line.

Fuel consumption determination

The fuel consumption rate was measured from both units (at a speed of 800-1500 rpm and 60% engine load for the main engine and at a speed of 1500 rpm and 40% engine load for the diesel generator), using observations of the level in the plastic hose of the oil tank. Fuel consumption was calculated for the corresponding power of the two engines. The brake specific fuel consumption (BSFC) was determined using Equation 1:

$$\text{BSFC} = \frac{\dot{m}_f}{P_b} \quad (1)$$

where:

\dot{m}_f = Fuel consumption rate (g/h)

P_b = Brake power (kW)

Thermal efficiency determination

The brake thermal efficiency (η_{tb}) was calculated from the power, heating values, and fuel consumption rate using Equation 2:

$$\eta_{tb} = \frac{P_b}{\dot{m}_f \times Q_{net}} \times 100 \quad (2)$$

where:

\dot{m}_f = Fuel consumption rate (g/s)

Q_{net} = Net heating value (kJ/g)

Emissions analysis

The exhaust gas of the main engine and the temperature of the exhaust gas were measured using a flue gas analyser™ (TESTO 300 M, Germany) that analyzed the CO content measured by a K-type thermocouple that was attached at the tip of the flue gas probe (at speeds of 800, 1100 and 1400 rpm with 60% engine load).

Effects on engine parts consideration

Terry (2005) was used as a guideline for the inspection of both the fuel injection pump and the injection nozzle. The fuel injection pump was inspected visually with a magnifying glass for signs of wearing, corrosion, soot and deposits, and clogging. The injection nozzle was tested for opening pressure and spray pattern with an Injection Nozzle Tester™ (BOSCH EFEP 60H, Germany). As with the fuel injection pump, the injection nozzle was investigated with a magnifying glass and cleaned subsequently. The opening pressure was adjusted and the spray pattern tested by the same type of Injection Nozzle Tester.

RESULTS AND DISCUSSION

Brake specific fuel consumption

The values of BSFC between B100 and B5 when the main engine was run at 60% engine load are shown in Figure 2 and indicate that the BSFC values of B100 were greater, when compared with B5. Based on the average values of BSFC, fuel consumption with B100 was greater than for B5 in the range 16.14-26.00%. The difference between the maximum and minimum BSFC values of B100 resulted from several uncontrollable factors in the operating conditions, such as the direction, velocity and level of the water flow in the river, which affected the BSFC values of B5, too.

The values of BSFC for B100 and B5, when used with a diesel generator at 40% engine load, are shown in Figure 3 and indicate that the BSFC values of B100 were greater, when compared with B5. Based on the average values of BSFC, fuel consumption with B100 was 26.55% greater than for B5.

There was greater fuel consumption with B100 than with B5 that resulted substantially from the lower heating value and higher density of B100 compared with B5 (Utlu and Kocak, 2008). The

significance of this work is that not only did it show that B100 had a higher fuel consumption than B5, but also that the measured values could be used in a comparison with other types of diesel engines using B100 or B5, as the fuel consumption was determined using BSFC.

Brake thermal efficiency

The values of η_{tb} between B100 and B5, when used with the main engine at 60% engine load are shown in Figure 4 and indicate that the η_{tb} value of B100 was lower compared with B5. Based on the average values of η_{tb} , B100 was lower than B5 in the range 0.55-7.68%.

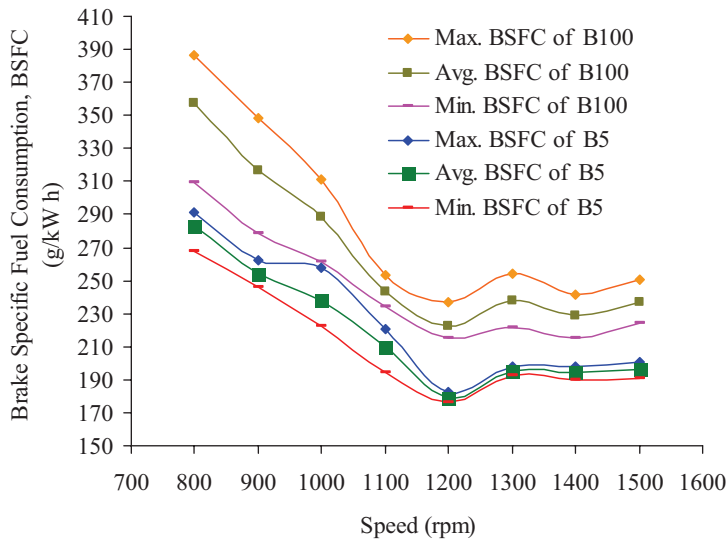


Figure 2 Comparison between the brake specific fuel consumption (BSFC) of B100 and B5, when used with the main engine at 60% engine load.

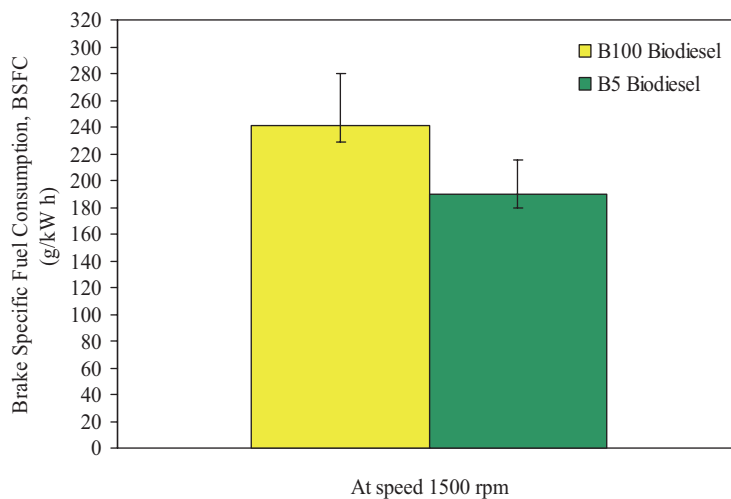


Figure 3 Comparison between brake specific fuel consumption (BSFC) of B100 and B5 when used with a diesel generator at 40% engine load.

The values of η_{tb} between B100 and B5 when used with a diesel generator at 40% engine load are shown in Figure 5 and indicate that the η_{tb} value of B100 was lower when compared with B5. Based on the averages values of η_{tb} , B100 was 8.58% less than B5.

The η_{tb} values were lower when B100 was used rather than B5, because of the higher viscosity and density and the lower heating value of B100, compared with B5 (Öner and Altun, 2009). The higher viscosity leads to decreased

atomization, fuel vaporization and combustion (Srivastava and Verma 2007; Banapurmatha *et al.*, 2008). Furthermore, the η_{tb} values of both B100 and B5 (Figures 3 and 4) are quite high, because values of the power of both engines were obtained from the manufacturing data, due to the difficulty of disassembling the engine (and the consequent reluctance of the engines' owner to allow this to be carried out) to install an engine dynamometer to measure the power values directly.

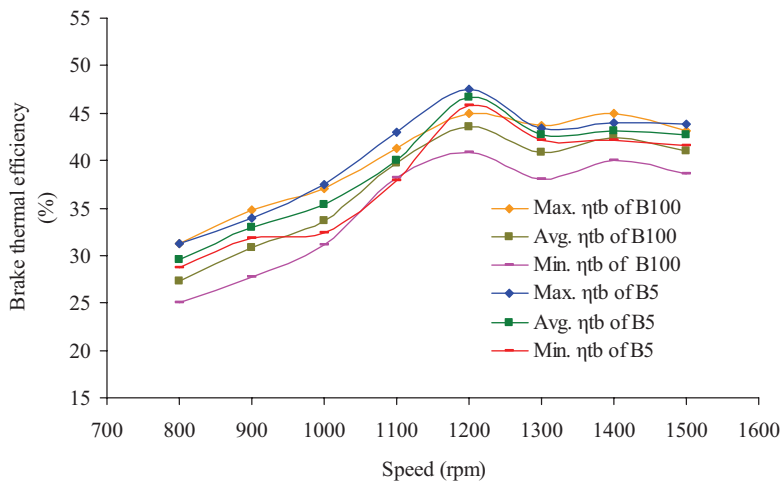


Figure 4 Comparison between brake thermal efficiency (η_{tb}) of B100 and B5, when used with the main engine at 60% engine load.

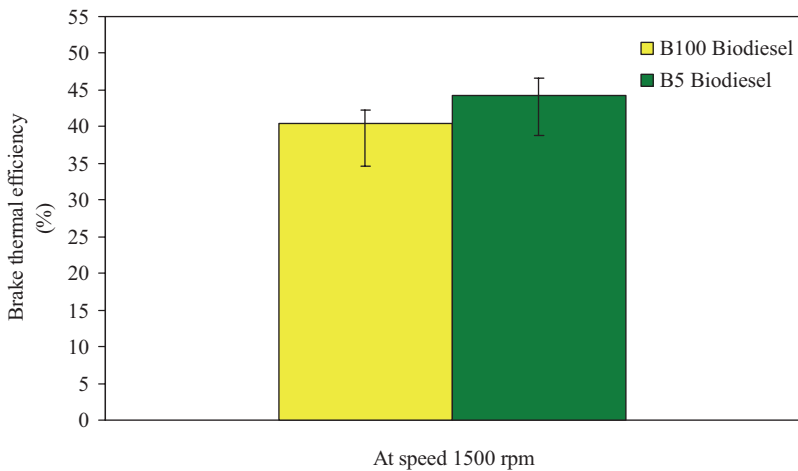


Figure 5 Comparison between brake thermal efficiency (η_{tb}) of B100 and B5, when used with a diesel generator at 40% engine load.

Exhaust gas temperature

Figure 6 shows the comparison between the exhaust gas temperature (EGT) of B100 and B5, when used with the main engine at 60% engine load and indicates that at a speed of 800 rpm, B100 had a higher EGT than B5. Based on average values, the exhaust gas temperature of B100 was 4.71% higher than B5. At speeds of 1100 and 1400 rpm, B100 had lower average values of EGT than B5 of 5.23 and 9.02%, respectively.

At speeds of 1100 and 1400 rpm, B100 had lower EGT values than B5, so that at most experimental speeds of the main engine, B100 had lower values of EGT than did B5. This resulted from the lower heating value of B100 when compared with B5 (Lin and Lin, 2006).

Emission of CO

Figure 7 shows the comparison between the CO content of B100 and B5, when used with the main engine at 60% engine load. At a speed of 800 rpm, B100 had a higher amount of CO than B5 that based on the average value was 11.09% higher. However, at speeds of 1100 and 1400 rpm, B100 had lower amounts of CO than B5, with average values lower by 4.84 and 27.25%, respectively.

At a speed of 800 rpm, B100 had a higher amount of CO than B5, while, contrarily, at speeds of 1100 and 1400 rpm, B100 had lower amounts of CO than B5. This can be explained by firstly, B100 having a higher flash point than B5, so that at a speed of 800 rpm (having a low exhaust temperature), B5 can be combusted more than B100 so that the CO content of B5 can be combusted more than for B100. However, at speeds of 1100 and 1400 rpm, (which have higher exhaust temperatures), the flash point is not a factor. Secondly, B100 has a higher oxygen content than B5 (Öner and Altun, 2009), which results in B100 having more complete combustion. Importantly, this work showed that in order to have a lower amount of CO in the flue gas from B100 than B5, the main engine should be operated at a speed not less than 1100 rpm.

Effects on fuel injection pump

The effects of B100 and B5 on the fuel injection pumps of the main engine and diesel generator are shown in Table 3. The roller tappet and other parts were evaluated for corrosion and it was found that the engine fueled by B100 had corrosion apparent in five out of six components in the roller tappet.

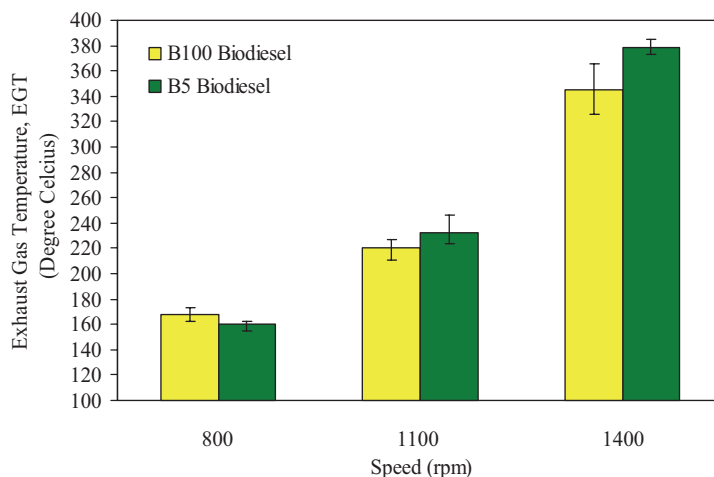


Figure 6 Comparison between exhaust gas temperature (EGT) of B100 and B5, when used with the main engine at 60% engine load.

Clogging of the strainer (about 50% by area) was found to be similar with both B100 and B5. Corrosion of the pump barrel is shown in the same way with roller tappet. And for soot and deposits was apparent in every component. Data on corrosion in an engine fueled with B5 was either not evaluated (one part) or no abnormality found (four parts).

Corrosion in the pump plunger and flange bushing in the engines fueled by B100 was apparent in three of six and four of six components, respectively.

The results in Table 3 indicate that there was not difference with regards to impact on the fuel injection pump of the main engine and diesel generator from using B100 or B5. The water content in the corrosion and soot and deposits found after using B100 was above 0.05% by weight, which is a limiting value (Government Gazette, 2009). Consequently, it appeared that the water sedimenter was unable to filtrate all of the water in the fuel, which resulted in a certain amount of the water leaking and reacting (oxidation) with the metal parts (Kaul *et al.*, 2007).

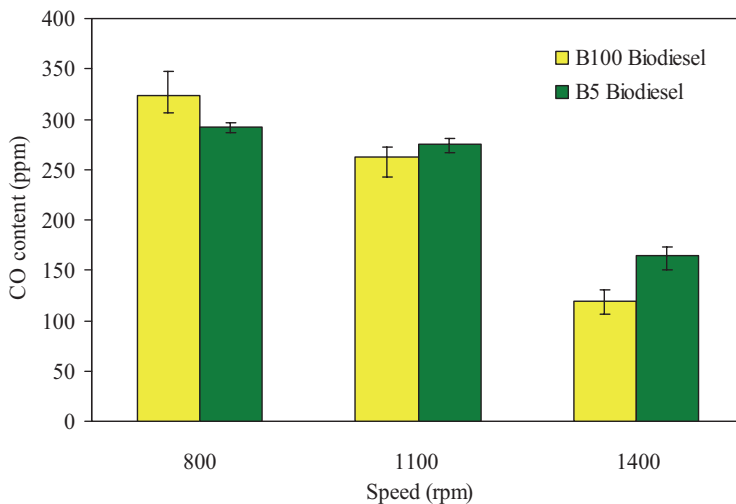


Figure 7 Comparison between CO content of B100 and B5, when used with the main engine at 60% engine load.

Table 3 Effect of B100 and B5 on the fuel injection pumps of main engine and diesel generator.

Part	Effect							
	Wearing		Corrosion		Soot and deposits		Clogging	
	B100	B5	B100	B5	B100	B5	B100	B5
Roller tappet	-	-	5/6	X	-	-	-	-
Strainer	-	-	-	-	-	-	50%	50%
Pump barrel	-	-	5/6	X	6/6	-	-	-
Pump plunger	-	-	3/6	X	-	-	-	-
Flange bushing	-	-	4/6	X	-	-	-	-

Remark: “ - ” = not evaluated or non-evaluable

“ X ” = no abnormality found

“ _/_ ” = proportion of the problem components

This problem can be corrected by improvements in the production process and storage to prevent B100 from coming into contact with outside moisture and oxygen, which are the main reasons that water appears in the fuel. Insolubles formed from minor components that often remain as precipitates in B100 at room temperature were reported to be the cause of clogging in engines (Tang *et al.*, 2008) and a similar effect should occur in engines with fueled B5, based on the limited efficiency of the fuel filter. There might have been the possibility that some insolubles had accumulated in the strainer, but this problem can be corrected by regular maintenance and replacement of the filter element, according to the specified period for engine maintenance. Importantly, this work indicated that more attention in the production process and storage of B100 was needed to provide a higher quality fuel.

Effects on injection nozzle

The effects of B100 and B5 on the injection nozzle of the main engine and diesel generator are shown in Table 4. Clogging of the nozzle hole with both B100 and B5 was similar, with a clogging percentage of about 20% of area. No abnormalities in the nozzle needle were found in either engine fueled with either B100 or B5.

The effect of B100 and B5 on the injection nozzle of the main engine and the diesel generator was the same for both engines (as for the fuel injection pump). Table 4 shows that B100 have very little negative effect on the injection

nozzle. B100 resulted in some clogging (20%) to the same degree as B5 and the cause of the engine clogging fueled with B100 was due to insolubles that formed from minor components that often remain as precipitates in the fuel at room temperature (Tang *et al.*, 2008). Together with the limited efficiency of the fuel filter, which would affect B5 also, there might be some possibility that some insolubles could leak into and accumulate in the nozzle holder. During fuel injection, the insolubles can become attached to the nozzle hole and cause clogging. This problem can be corrected by regular maintenance and filter element replacement according to periodic engine maintenance specifications. This observation indicates that more attention was needed in maintenance processes to produce higher working performance in the engines.

CONCLUSION

The study was carried out to investigate the fuel consumption, thermal efficiency, emissions and effect on engine parts when engines used B100 fuel compared with B5 fuel under field operating conditions. Engines using B100 had higher break specific fuel consumption and lower break thermal efficiency when compared with B5-fueled engines. B100 was effective at reducing CO emissions levels at medium engines speeds and was expected to be equally effective at higher engine speeds. In addition, corrosion with soot and deposits resulting from the use of B100 fuel should

Table 4 Effect of B100 and B5 on injection nozzles of main engine and diesel generator.

Part	Effects							
	Wearing		Corrosion		Soot and deposits		Clogging	
	B100	B5	B100	B5	B100	B5	B100	B5
Nozzle hole	-	-	-	-	-	-	20%	20%
Nozzle needle	X	X	X	X	X	X	X	X
Nozzle holder	-	-	-	-	-	-	-	-

Remark: “ - ” = not evaluated or non-evaluable

“ X ” = no abnormality found

be comparable with B5 fuel, if the production process and storage can be improved to prevent contact of the B100 fuel with outside moisture and oxygen, which were the main reasons for the water content. Thus, B100 could be utilized as a renewable and low-pollution alternative fuel for direct injection diesel engines.

ACKNOWLEDGEMENTS

The authors acknowledge the Naval Dockyard Department, PTT Public Company Limited and Captain Dr Samai Jai-in R.T.N. for providing the opportunity to participate in this project. The Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University is thanked for providing laboratory equipment and support for some applications used in this research. Entech Associate Co., Ltd, together with Thai Kolon Co., Ltd provided some technical data.

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