The Tribological Behavior of Biodiesel in Ethanol-Diesel Blends

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Abstract

Among the proposed alternative fuels, biodiesel- and ethanol-diesel blends have been received much attention for diesel engines due to advantages as the renewable and domestic energy resources. However, major drawbacks of ethanol-diesel blends are the poor miscibility and the large difference in viscosity between ethanol and diesel fuel. These limitations result in lubricity of blended fuel. Biodiesel, an amphiphile or a surface-active agent, is known as an additive to improve the lubricity of diesel fuel. It has been used as an emulsifier for ethanol-diesel emulsions. Therefore, this research focused on the impact of biodiesel on the lubricity of ethanol-diesel blends. Tribological behavior of the ethanol-diesel-biodiesel blends was investigated by the High Frequency Reciprocating Rig (HFRR). The result showed that the addition of biodiesel in the ethanol-diesel blends was found to improve the lubricity of blends as compared to diesel fuel. An increased amount of ethanol in the blends could promote the film stability of ethanol-diesel emulsion, resulting in increased the wear resistance.

***Keywords**:* Lubricity, Biodiesel, Ethanol, Emulsion, High Frequency Reciprocating Rig (HFRR)

1. Introduction

Due to the rapid depletion of natural fossil fuel reserves, researches and development of renewable energy for automobile have been increasingly interested in recent years. Among the proposed alternative fuels, biodiesel- and ethanol-diesel blends have been received much attention for diesel engines due to their advantages as the renewable and domestic energy sources. However, using ethanol blended fuels in diesel engines has many drawbacks: phase separation and low flash point [1, 2]. Ethanol and diesel fuel are inherently immiscible because of their difference in chemical structures and characteristics [3]. Therefore, ethanol-diesel blends require an additive acting like an emulsifier to stabilize their miscibility as emulsion. The emulsifier will reduce the interfacial tension force and increase the affinity between two liquid phases [4]. Many additives have been developed to prevent the phase separation of ethanol-diesel blends [5]. However, most of them are costly and need to be imported. A suitable emulsifier for ethanol and diesel fuel should contain lipophilic part and hydrophilic part. Such chemical structures are obtained in biodiesel which can be found in agricultural based countries.

In diesel engine, diesel fuel is not only used the source of energy but also lubrication of fuel injection pump. Traditionally, petroleum fuel viscosity can be used as an indicator for a fuel to provide wear protection. Diesel lubricity comes naturally from occurring polar compounds, which form a protective layer on the metal surface. Heterocyclic aromatics and nitrogen/oxygen compounds (rather than sulfur) were reported to cause most important for lubricity [6]. A critical threshold of polar compounds was necessary for good lubricity. The addition of higher alcohols (e.g., octanol and oleyl alcohol) to diesel has been developed to compensate for the deterioration in natural lubricity observed in low sulfur fuel [7]. Very few lubricity tests on ethanol-diesel blends have been published.

This research focused on the use of biodiesel as an additive for stabilizing the solubility of ethanol-diesel blends. The phase stability and fuel properties (e.g., density, viscosity and lubricity) of the blends at various concentrations were studied in comparison with Thai commercial diesel.

2. Experimental Procedure

To prepare the ethanol-diesel-biodiesel blends, regular diesel was obtained from PTT Public Co., Ltd. (Bangkok, Thailand). Ethanol was an anhydrous grade (99.5% vol purity) while biodiesel was derived from palm oils. The blending protocol was explained as follow. Firstly, biodiesel was mixed with ethanol to obtain homogeneous phase of the solution. Biodiesel of 3% vol was mixed into the blends. Then, they were blended with diesel and formed into ethanol-diesel-biodiesel blends. The concentration of diesel and ethanol (D:E) were varied at 95:5, 90:10 and 85:15 %vol, where 'diesel' is denoted as 'D' and 'ethanol' is denoted as 'E'.

3. Results and Discussions

3.1 Density and viscosity

To study the effects of biodiesel in the emulsions, the properties of all test samples were conducted according to American Society for Testing Materials (ASTM) standard. The density of reference substances showed 0.823 g/cm^3 for diesel, 0.864 g/cm^3 for biodiesel and 0.794 g/cm^3 for ethanol (purity 99.5%). The viscosity of reference substances showed 3.19 cSt for diesel, 5.321 cSt for biodiesel and 1.19 cSt for ethanol (purity 99.5%). The fuel properties of emulsions (D:E) at 95:5, 90:10 and 85:15 %vol containing 3% vol of biodiesel are presented in Table 1.

Table. 1 Fuel properties of ethanol-diesel-biodiesel blends

Properties	Diesel:Ethanol (%volume)			Testing Method (ASTM)
	D95/E5	D90/E10	D80/E20	
1. Density (g/cm^3)	0.8391	0.8297	0.8239	D1298
2. Viscosity @ 40 $^{\circ}$C (cSt)	3.064	2.947	2.597	D445
3. Fuel stability	1[a]	2[b]	3[c]	-

[a]Clear liquid 1 phase is a single phase liquid system; [b]Clear liquid 2 phases is a double-phase liquid system. No crystals or particles are observed; [c]Liquid crystalline 1 phase is a single-phase liquid system. The whole system looks cloudy or turbid and flows like a liquid.

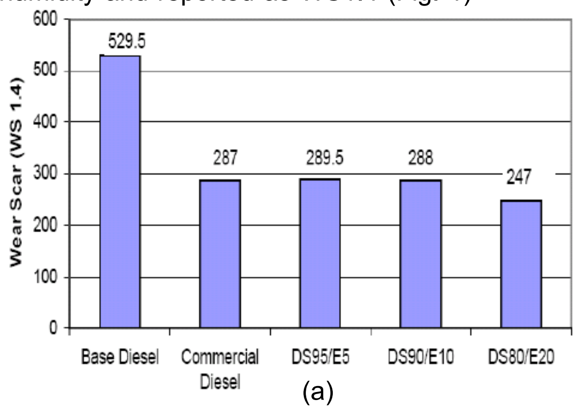
Viscosity is an important fuel property because it affects the atomization of a fuel upon injection into the diesel engine combustion chamber and, ultimately, the formation of engine deposits. Fuels with higher viscosities are more likely to cause such problems. In the current study, density and viscosity of emulsions at 40 °C decreased with increasing amount of ethanol (Table 1). This is attributed to the fact that ethanol has lower density than those of other two components. It is well known that the lower density leads to a decrease in flow resistance of the fuel, resulting in lower viscosity. Viscosity of all emusions (at 40 °C) was lower than that of the diesel fuel due to the lower viscosity of ethanol concentration. As a result, the viscosities of all emulsions in this research are located in a standard limit for diesel fuel in Thailand. It is noted that the viscosity of diesel standard is 1.8-4.1 cSt while the density standard is 0.81-0.87 g/cm^3 [8].

3.2 Fuel stability

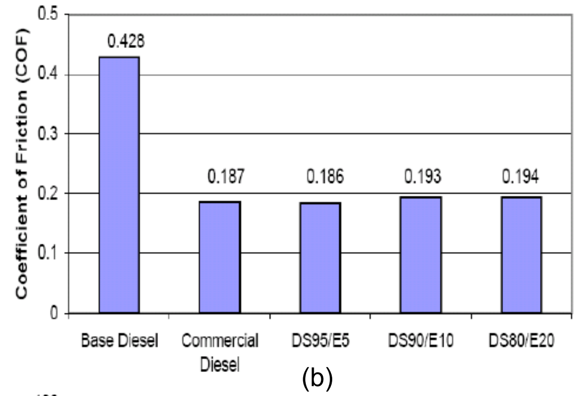
In order to investigate the fuel stability in Table 1, all ethanol-diesel emulsions were kept in storage and left for 3 months at room temperature. The result shows that only emulsion at the percentage of D:E as 95:5 %vol exhibits stability of solubility. No agglomeration of liquid droplets and sediment layer were observed in this ratio. By contrast, the concentration ratios of diesel and ethanol of 90:10 and 80:20 %vol appeared phase separation and agglomeration of liquid droplets after stored for 3 months as shown in Table 1. From the results, it is suggested that biodiesel is a suitable emulsifier for ethanol-diesel blends at low ethanol content.

3.3 Lubricity of ethanol-diesel-biodiesel blends

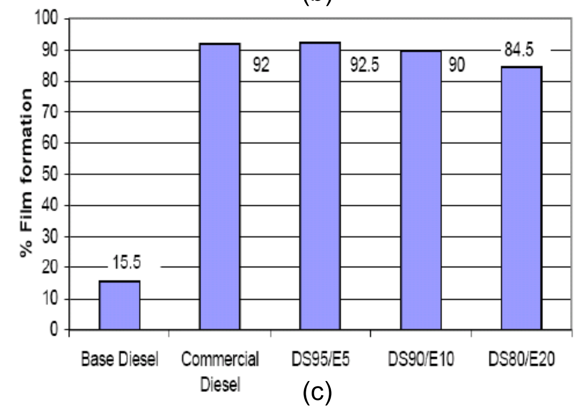
The lubricity of blended fuels was measured by means of high frequency reciprocating rig (HFRR) method. The testing parameters and conditions are followed CEC-F-06-A-96 standard. The ball specimen is oscillated and rubbed against the fixed flat plate, resulting in the coefficient of friction. Both specimens are submerged in the testing oil which forms the film between ball and plate. After the test was completed, the wear scar on the ball was measured manually by means of an optical microscope. Then, wear scar diameter was corrected with the ambient temperature and humidity and reported as WS1.4 (Fig. 1)



(a)



(b)



(c)

Fig. 1 Effect of 3% vol of biodiesel on WS1.4 (a), COF (b) and the percentage of film formation (c)

As seen in Fig.1, commercial diesel in Thailand which contains 3% vol of biodiesel during the current study has a lower WS1.4 and COF when compared with base diesel. Adding a small quantity of biodiesel could promote the lubricity of fuels [9]. Hence, a significant drop in both wear scar and COF values were observed (Fig. 1 (a) and (b)). It is likely that the molecular layer was formed by the adsorption of the lubricant (or biodiesel) on the worn surfaces. The polarity of the absorbate is essential to the lubrication mechanism. This corresponds with the increasing percentage of film formation when adding biodiesel in fuels as shown in Fig. 1(c). The higher percentage of film formation means the lesser chance of ball to directly contact plate and vice versa for lower percentage of film formation.

Like commercial diesel, adding 3% of biodiesel can enhance the lubricity of ethanol-diesel blends. However, adding 3% biodiesel may not be sufficient to stabilize at all ratios of diesel fuel to ethanol. The higher film thickness at D:E 95:5 %vol relative to the other ethanol-diesel blends (Fig. 1(c)) were in good agreement with the fuel stability of ethanol-diesel blends (Table 1). This results an increase in COF value with the amount of ethanol. By contrast, the wear scar value of a test specimen in the ethanol-diesel emulsion decreases with increasing the amount of ethanol. This can be explained by the lubricated film stability in the ethanol-diesel emulsions as shown in Fig. 2 and 3.

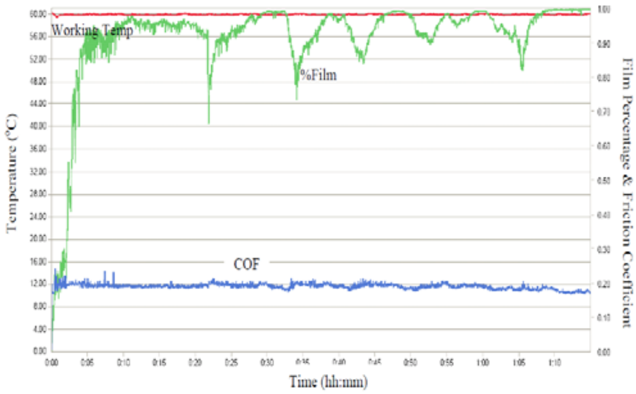


Fig. 2 Effect of 3% vol biodiesel contained in commercial diesel on WS1.4, COF and the percentage of film formation

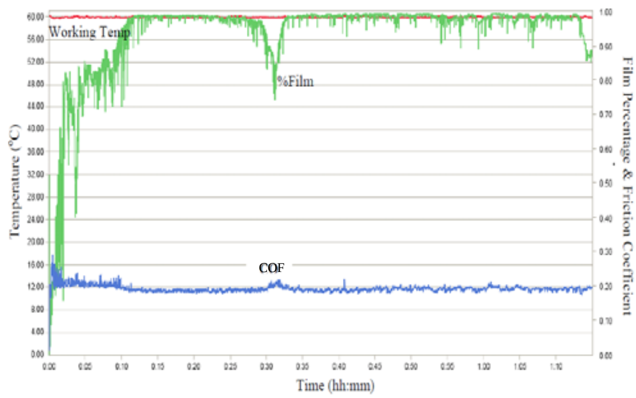


Fig. 3 Effect of 3% vol biodiesel added in ethanol-diesel blend (D:E 95:5 %vol) on WS1.4, COF and the percentage of film formation

As shown in Fig. 2 and 3, the lowest film stability was found in Thai commercial diesel (contained 3% biodiesel) compared to the ethanol-diesel fuel blends. This implies that OH group of ethanol could promote the film stability of ethanol-diesel emulsion. The film stability increases with the amount of ethanol, resulting in increased the wear resistance.

4. Conclusions

1. Viscosity and density of all ethanol-diesel emulsions are in Thailand's diesel standard.

2. Biodiesel, derived from palm-oil, can be used as an effective emulsifier for ethanol-diesel emulsions. At low percentage of ethanol, ethanol blended fuels can be stored at room temperature for 3 months without any phase separation and agglomeration of liquid droplets.

3. Lubricity of diesel can be improved by biodiesel addition which corresponds with the high percentage of film formation.

4. Ethanol can promote the lubricated film stability of the ethanol-diesel emulsions, corresponding with the wear resistance.

5. Acknowledgement

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6. References

[1] Ecklund, E.E., Bechtold, R.L., Timbario, T.J. and McCallum, P.W. (1984). State-of-the-Art Report on the Use of Alcohols in Diesel Engines, Development of coated, annular fins for adsorption chillers, SAE Paper No. 840118.

[2] Waterland, L.R., Venkatesh, S. and Unnasch, S. (2003). Safety and Performance Assessment of Ethanol/Diesel Blends (E-Diesel), Subcontractor Report, NREL/SR-540-34817.

[3] Jackson, M.M., Cockwell, C.K. and Degroote, C.C. (2003). Study of Diesel and Ethanol Blends Stability, SAE Paper No. 2003-01-3191.

[4] Lin, C.Y. and Wang, K.H. (2003). The Fuel Properties of Three Phase Emulsions as an Alternative Fuel for Diesel Engines, *Fuel*, vol.82, pp. 1367 – 1375.

[5] Ahmed, I. (2001). Oxygenated Diesel: Emissions and Performance Characteristics of Ethanol-Diesel Blends in CI Engines, SAE Paper No. 2001-01-2475.

[6] Wei, D.P. (1990). The Lubricity of fuels. I. Wear studies on diesel fuel components, *Acta Petrolei Sinica*, vol.2, pp. 79 – 87.

[7] Anatopoulos, G., Lois, E., Zannikos, F., Kalligeros, S. And Teas, C. (2002). The Tribological behavior of alkyl ethers and alcohols in low sulfur automotive diesel, *Fuel*, vol.81, pp. 1017 – 1024.

[8] Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand (2004). *Diesel Standard*, URL: http://www.doeb.go.th/dtanotice/cancle-diesel25-01-56.pdf, access on 01/06/2013

[9] Topaiboul, S., Chollacoop, N. and Treesuwan, K. (2007). Biodiesel from Various Vegetable Oils as the Lubricity Additive, paper presented in *the 21st Conference of Mechanical Engineering Network of Thailand.*