

Evaluation of Biodiesel Tribological Performance under Reciprocating Sliding Conditions

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Abstract—In this work, the distilled biodiesel of waste cooking acids methyl esters (WCME) was blended with petroleum diesel as testing fuels (D100/DB2/DB5/DB20/DB100). The tribological performance of the biodiesel was evaluated using a reciprocating cylinder-on-flat wear test rig (Cameron-Plint TE-77) at various temperatures (room temperature and 80°C). After the wear test, the worn surface of each tested specimen was observed using a scanning electron microscope (SEM). The compositions of the chemical films on each worn surface were determined using an energy dispersive spectrometer (EDS). The experimental results demonstrate that the tribological behavior of the DB100 was superior to that of the other testing fuels. Lubricity of the test sample was increased as a consequence of increasing biodiesel concentration, which caused by the quantity of the methyl esters in the test sample.

Keywords—biodiesel; waste cooking acids methyl esters; tribological performance; wear

I. INTRODUCTION

Recently, protecting the global environment and the concern for long-term supplies of conventional diesel fuel, it has become necessary to develop alternative fuels. The diesel fuel also affects the performance of engine. Biodiesels are applied frequently as lubricants for transmission components because it contains fatty acid esters. In some situations, lubricants cannot be directly used for certain mechanical systems, such as a nozzle of diesel engines. Some studies have indicated that biodiesel has many advantages over petroleum diesel [1-2], including more effective lubricity [3]. However, biodiesel could increase the acid value so that it makes the engine fuel easily degrade [4-6]. Therefore, it is necessary to explore the effect of biodiesel that is fading in storage on tribological performance. In this study, the tribological performance of biodiesel is evaluated by performing reciprocating sliding wear tests under various conditions.

II. EXPERIMENT

Reciprocating sliding wear tests were performed in cylinder-on-flat mode using a Cameron-Plint TE77 tribometer to evaluate the tribological performance of the test fuels. During the test, the frictional force was monitored continuously using a data acquisition system that comprised a PC and an NI USB-9161 transfer card. Table 1 presents abbreviation code and constituents of the test fuels. For example, the blended fuel that contained 2wt.% distilled biodiesel and 98wt.% petroleum diesel (D100) is denoted as DB2. Table 2 presents the parameter

of wear test. The wear test conditions were kept a mean sliding speed of 0.066 m/s, a load of 150 N, a sliding distance of 713 m in 3 hours, and fuel bath temperatures of room temperature (25°C) and 80°C, separately. The test temperature was set to 80°C to simulate the operating temperature of the nozzle of diesel engine. The sliding cylinder specimen was made of AISI 52100 (6(D) × 6(L), with a hardness of H_V745) and the stationary plate specimen was made of AISI 1045 (58(L) × 38(W) × 4(H), with a hardness of H_V235).

TABLE I. THE CONSTITUENTS OF THE VARIOUS TEST FUELS

Test fuel \ Ingredients	0%	2%	5%	20%	100%
Distilled Biodiesel	D100	DB2	DB5	DB20	DB100

*Biodiesel were blended with petroleum diesel as testing fuels.

TABLE II. THE PARAMETER OF WEAR TEST

	Cameron-Plint TE-77
Simulation target	Engine parts (Nozzle)
Load	150 N
The maximum contact stress	540 MPa
The average sliding velocity	0.066 m/s
Stroke	6 mm
Sliding distance	713 m
Temperature	25°C, 80°C
Time	3 hours

III. RESULTS AND DISCUSSIONS

A. Friction Behavior at Room Temperature (25°C)

At room temperature (25°C), the specimen tested in petroleum diesel (D100) has the highest friction coefficient than the others. Increasing percentage of distilled biodiesel could decrease the friction coefficient, as shown in Figure 1(a)~(e). Because fatty acid methyl ester, which is present in the biodiesel, can adsorb onto the surface, promoting the lubricating effect on the rubbing surface so that it can avoid asperities adhesion.

B. Worn surface Morphology test at Room Temperature (25°C)

The worn surface of specimen, which tested in petroleum diesel (D100) indicates that the main wear mechanism is adhesive wear, Figure 2(a). However, increasing the concentration of the distilled biodiesel, the main wear

mechanism became abrasive wear, as displayed in Figure 2 (b)~(e). Including higher concentration biodiesel, the adsorption film was more complete than that of the petroleum diesel. The contents of fatty acid methyl ester with increasing percentage of distilled biodiesel so that it could protect the rubbing surface. Therefore, the abrasive wear and adhesive wear in the petroleum diesel specimen was more serious than that of the specimen tested in the biodiesel.

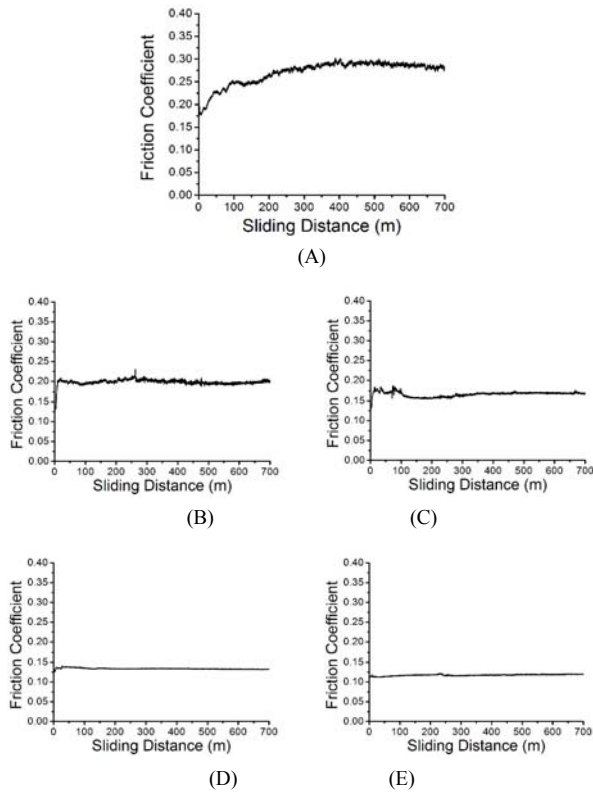


FIGURE I. FRICTION BEHAVIOR OF DISTILLED BIODIESEL AT 25°C : (A)D100 (B)DB2 (C)DB5 (D)DB20 (E)DB100

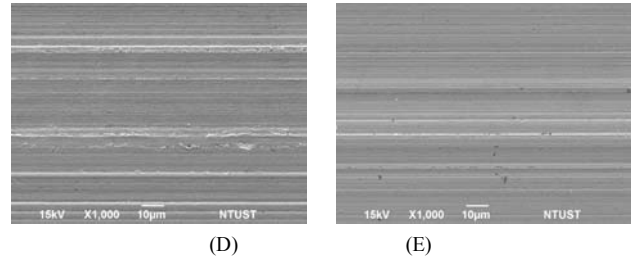
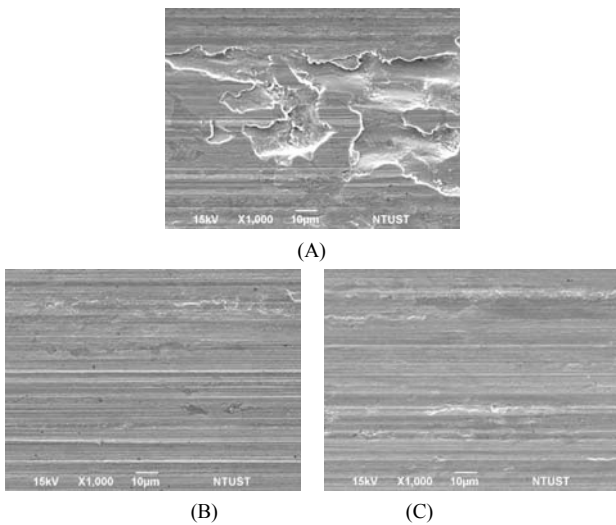


FIGURE II. SURFACE MORPHOLOGY OF THE SPECIMEN USING DISTILLED BIODIESEL AT 25°C : (A)D100 (B)DB2 (C)DB5 (D)DB20 (E)DB100

Using energy dispersive spectrometer (EDS) to detect different kinds of chemical element from worn surface after wear test. The most element content on worn surface are mainly in carbon(C), oxygen(O), ferrite(Fe) and without any other chemical elements, as shown in Figure 3.

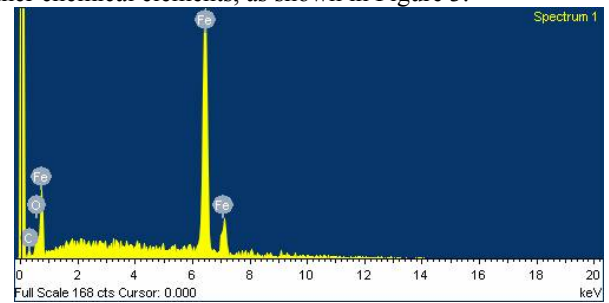


FIGURE III. EDS OF THE SPECIMEN USING DISTILLED BIODIESEL AT 25°C

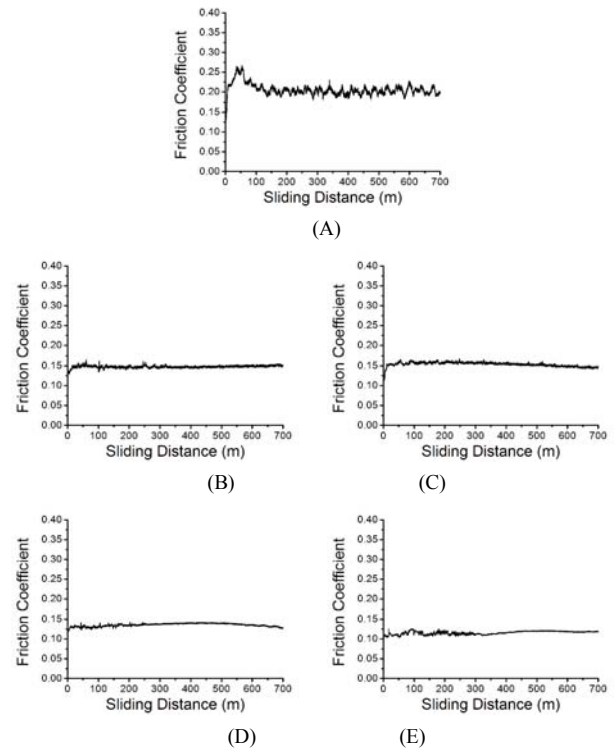


FIGURE IV. FRICTION BEHAVIOR OF DISTILLED BIODIESEL AT 80°C : (A)D100 (B)DB2 (C)DB5 (D)DB20 (E)DB100

C. Friction Behavior at 80 °C

At 80°C, the specimen which is tested in petroleum diesel (D100) has most high friction coefficient than others. Along with increasing percentage of distilled biodiesel that could decrease the friction coefficient, as shown in Figure 4 (a)~(e), because fatty acid methyl ester, which is present in biodiesel, is adsorbed onto the surfaces, promoting the lubrication between the rubbing surfaces so that can avoid each rough surface peak of asperities adhesion. However, the ability of protecting rubbing surface by fatty acid methyl ester would decrease especially as in the high temperature; Besides, the viscosity of the test fuels is lower, so the interference of the asperities was increased under boundary lubrication conditions. In general, the friction coefficients in 80°C are more unstable than that of tested at room temperature (25°C)

D. Worn Surface Morphology test at 80 °C

At 80°C, the wear surface morphology are severely than that of tested at room temperature. The worn surface of specimen which tested in petroleum diesel (D100)、biodiesel blended with petroleum diesel in 2% and 5% indicate that the main wear mechanism is adhesive wear, as shown in Figure 6(a)~(c). Along with increasing the concentration of the distilled biodiesel indicate that abrasive wear is the main wear mechanism became abrasive wear, as displayed in Figure 6(d)~(e). The contents of fatty acid methyl ester with increasing percentage of distilled biodiesel so that could protect on each rough surface peak of asperities without adhesion. Therefore, it can decrease contact stress of material and more difficult to let the local yielding occurred, so formed scratches are shallower. However, the viscosity of the fuel and the ability of protecting rubbing surface by film adsorption would decrease in high temperature condition. During run-in period, the asperities breaking led to the surface roughening. After the run-in process, plastic deformation of the contact surface increased the real contact area of the test specimens and to reduce the contact stress. The abrasive wear and adhesive wear in the petroleum diesel specimen was more serious than that of the specimen tested in the biodiesel at higher temperature, comparing Figure 2 and Figure 5.

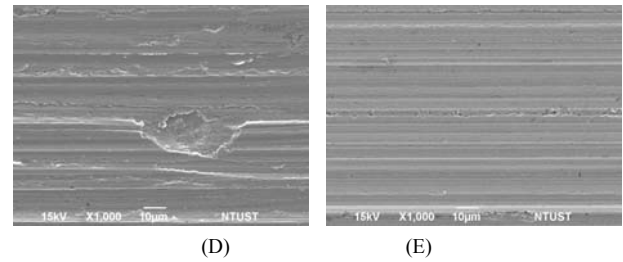
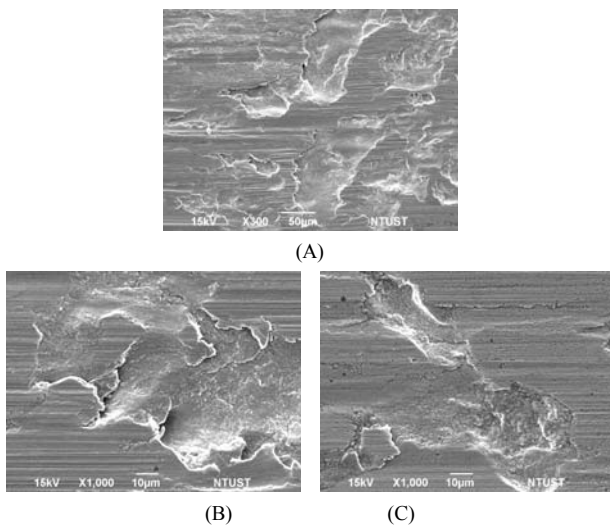


FIGURE V. SURFACE MORPHOLOGY OF THE SPECIMEN USING DISTILLED BIODIESEL AT 80°C: (A)D100 (B)DB2 (C)DB5 (D)DB20 (E)DB100

Using energy dispersive spectrometer (EDS) to detect different kinds of chemical element from worn surface after wear test. The most element content on worn surface are mainly in carbon(C), oxygen(O), ferrite(Fe) and without any other chemical elements, as shown in Figure 6.

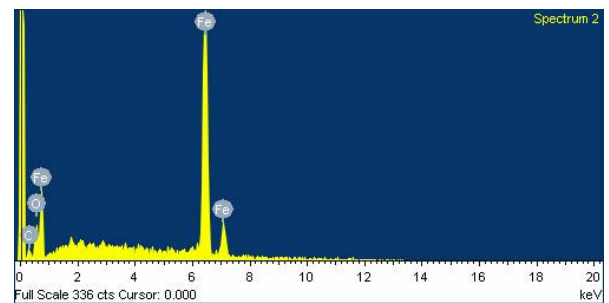


FIGURE VI. EDS OF THE SPECIMEN USING DISTILLED BIODIESEL AT 80°C

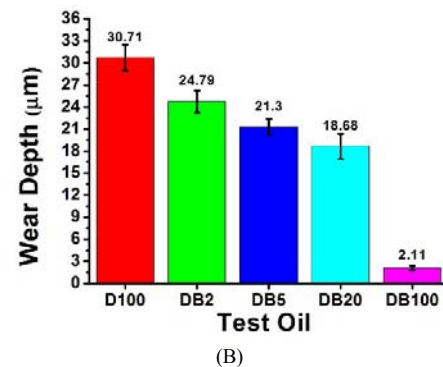
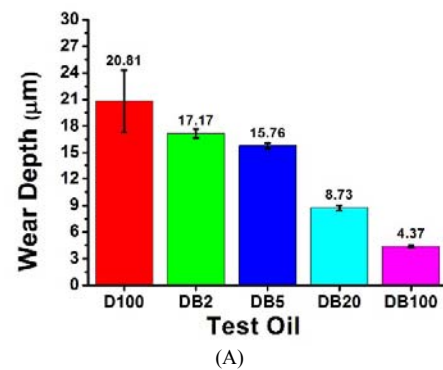


FIGURE VII. WEAR DEPTH OF THE PLATE SPECIMENS TEST IN DISTILLED BIODIESEL: (A)AT 25°C (B)AT 80°C

E. Wear Behaviors under Different Temperature Conditions

Comparing Figure 7(a) and (b). From the experimental results, the depth of the wear scar in petroleum diesel and distilled biodiesel at 80°C exceed that of tested at room temperature (25°C). Increasing the temperature, it resulted in the physical adsorption film by fatty acid methyl ester weakened. Moreover, raising temperature caused the reduction of the micro hydrodynamic effect, and then increases the wear depth. It's worth mentioning that the distilled biodiesel (DB100) at 80°C had the lowest wear depth among all specimens. It is possible that some oxides protected the rubbing surface to prevent the direct contact of rough surface during wear test.

IV. CONCLUSIONS

This investigation explores the tribological performance of three tested fuels. Distilled biodiesel (DB100) exhibited the best anti-wear performance, based on the wear depth of tested specimens. Sliding wear test results demonstrated that test in biodiesel and room temperature (25°C) biodiesel had the best tribological performance, in which the fatty acid methyl ester dominated the anti-wear ability, and the rubbing surface of the specimen was covered by physical adsorption film more completely. However, viscosity of fuel and the ability of protecting rubbing surface by film absorb would decrease in higher temperature condition so that we can perceive that the wear depths in petroleum diesel and distilled biodiesel at 80°C exceed that of tested at room temperature. Especially, the pure biodiesel (DB100) has the lowest depth of the wear scar that shows it has best anti-wear ability compared with the other tested samples. It is possible that some oxides protected the rubbing surface to prevent the direct contact of rough surface during wear test.

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