Glycerol Monooleate (GMO): A Valuable Biobased Lubricity and Pour Point Enhancer Blend Component for the ULSD Fuel

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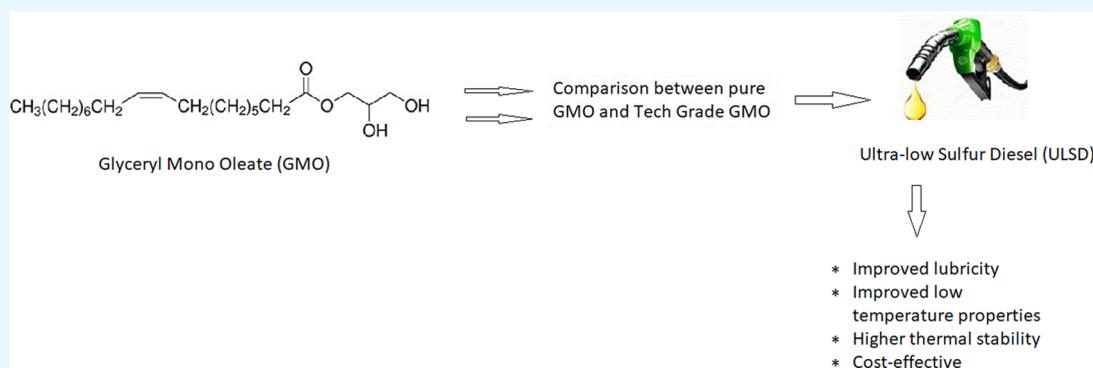
ABSTRACT: Novel value-added usage of glycerol (biodiesel coproduct) derivatives has been indispensable due to the extensive production of biodiesel. The physical properties of ultralow-sulfur diesel (ULSD) improved with the addition of technical-grade glycerol monooleate (TGGMO) with increasing concentration from 0.01 to 5 wt %. The influence of increasing concentration of TGGMO was studied on the acid value, cloud point, pour point, cold filter plugging point, kinematic viscosity, and lubricity of its blend with ULSD. The results showed improved lubricity for the blended ULSD with TGGMO as shown by the reduced wear scar diameter from 493 to 90 μm. The low-temperature flow properties were also improved as shown by lower pour points of −36 °C for the 1% TGGMO/ULSD blend compared to −25 °C for ULSDTGGMO blends in ULSD of up to 1 wt %, which met the ASTM standard D975 specifications. We also investigated the blending effect of the pure-grade monooleate (PGMO, purity level >99.98%) on the physical properties of ULSD at a blend concentration of 0.5 and 1.0%. Compared to PGMO, TGGMO significantly improved the physical properties of ULSD with increasing concentration from 0.01 to 1 wt %. Nevertheless, PGMO/TGGMO did not significantly affect the acid value, cloud point, or cold filter plugging point of ULSD. A comparison between TGGMO and PGMO showed that TGGMO improves the ULSD fuel lubricity and pour point more effectively than PGMO. PDSC data indicated that although addition of TGGMO will lower the oxidation stability slightly, it is still better than the addition of PGMO. Thermogravimetric analysis (TGA) data showed higher thermal stability and lesser volatility for TGGMO blends compared to those for PGMO blends. The cost effectiveness of TGGMO makes it a better ULSD fuel lubricity enhancer than PGMO.

1. INTRODUCTION

An attractive blend constituent or substitute to petroleum diesel fuel (petrodiesel) is biodiesel, defined as a fuel consisting of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats.[1,2] Biodiesel has recently experienced an upward surge worldwide, not only in advanced countries such as the USA, Germany, France, and Italy but also in developing countries such as Malaysia, Indonesia, Brazil, and Argentina.[3] As a result, a large amount of surplus glycerol (biodiesel coproduct, ~10% of the total biodiesel production) was generated. For biodiesel producers to be competitive, viable, value-added utilization of glycerol is solicited. Since 2006, the EPA has mandated that diesel fuel used for transportation applications should have an extremely low amount (<15 ppm) of sulfur, resulting in ultralow-sulfur diesel

fuel (ULSD). The major benefit of changing to ULSD is that the environmental impact of sulfur dioxide emissions is reduced.[4] However, decreasing the amount of sulfur in diesel created lubricity (premature fuel pump and injector wear) and cold flow property issues. Recently, we have reported different nonedible oil-based biodiesels and studied the effects of their blending with ULSD[5,6] and reported glycerol derivatives as

diluents to improve low-temperature properties of the vegetable oils to discover value-added exploitation of the biodiesel coproduct (glycerol).[7] Recently, we have also reported the origin of biodiesel lubricity and the lubricity of components of biodiesel and petrodiesel.[8]

To solve the issue of lubricity due to the reduced amount (15 ppm) of sulfur in ULSD and to find value-added utilization of glycerol (biodiesel coproduct), our current work of blending TGGMO into ULSD is being undertaken in continuation of our previous work.[5−8] After learning that TGGMO can improve ULSD lubricity by blending, it became interesting to explore the impact of 99.98% PGMO. The chemical structure of pure-grade monooleate (PGMO)/glycerol mono-oleate (GMO) is shown in Figure 1.
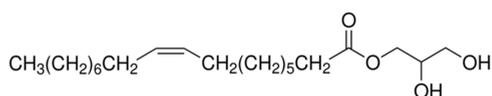
Figure 1. Pure-grade monooleate (PGMO)/glycerol monooleate (GMO).

The outcome of blending TGGMO/PGMO into ULSD was determined by studying its influence on the different physical properties, such as acid value, cloud point, pour point, cold filter plugging point, kinematic viscosity, thermal/oxidative stability, and lubricity of the blend, with increasing concentration of TGGMO/PGMO. The above-mentioned properties were determined by means of conventional methods such as ASTM standard methods and AOCS official methods. Lastly, evaluation of the results of blending TGGMO/PGMO with ULSD to be acceptable according to biodiesel fuel standards (Tables 1−3) such as ASTM D6751[2] and EN 590[9] was of additional interest.

Table 1. Selected Specifications from ASTM D975-07b and EN 590 Diesel Standards

specification	ASTM D975-07b	EN 590
AV, mg KOH/g		0.50 max
CP, °C	depends[aa]	
PP, °C		
CFPP, °C	depends[aa]	depends[aa]
v, 40 °C, mm²/s	1.9–4.1	2.0–4.5
lub, μm (HFRR)	520 max	460

[a]Depends on the location and time of year.

2. EXPERIMENTAL SECTION

2.1. Materials. TGGMO technical-grade (CAS No. 111-03-5) GMO [~40% monoglyceride (TLC), 20−40% digly-ceride (TLC) and 20−40% triglyceride (TLC)] and PGMO [CAS No. 111-03-5 purity level >99.98% monoglyceride (TLC)] purchased from the Fluka Analytical Division of Sigma-Aldrich Corp. (St. Louis, MO) were used as received. ULSD was donated by a major petrochemical company. Conductivity and corrosion inhibitor additives were added by the manufacturer to the ULSD, but no drag reduction, lubricity, low-temperature, or antioxidant additives were present.

2.2. Preparation of Blends. *2.2.1. Preparation of TGGMO/ULSD Blends.* TGGMO was added to ULSD at

0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 2.0, 5.0, 7.5, 10, 15, and 20% (vol), resulting in 16 TGGMO/ULSD blends.

2.2.2. Preparation of TGGMO/ULSD and PGMO/ULSD Blends. PGMO and TGGMO blends were prepared in ULSD at 0.5 and 1.0% (vol), resulting in two TGGMO/ULSD blends and two PGMO/ULSD blends.

2.3. Fuel Properties. *2.3.1. Acid Value (AV).* The acid value (AV, mg KOH/g) was measured (triplicates, means reported) following the AOCS official method Cd 3d-63[10] using a Metrohm 836 Titrando (Westbury, NY) autotitrator equipped with a model 801 stirrer, a Metrohm 6.0229.100 Solvotrode, and Tiamo 1.1 Light software. The official method was modified for scale to use 2 g of sample and 0.02 M KOH. The titration endpoint was determined using the instrument and visually verified using a phenolphthalein indicator.

2.3.2. Cloud Point (CP) and Pour Point (PP). Cloud point (CP, °C) and pour point (PP, °C) determinations were made in agreement with ASTM D5773[11] and ASTM D5949,[12] respectively, using a Phase Technology analyzer model PSA-70S (Richmond, BC, Canada). The CP was rounded to the nearest whole degree. For a greater degree of accuracy, the pour point was measured with a resolution of 1 °C compared to the 3 °C increase specified in the official method.

2.3.3. Cold Filter Plugging Point (CFPP). The cold filter plugging point (CFPP, °C) was determined in accordance with ASTM D6371[13] utilizing an ISL Automatic CFPP analyzer model FPP 5Gs (PAC L.P., Houston, TX). Each sample was run in triplicate, and mean values are reported.

2.3.4. Kinematic Viscosity (v). Kinematic viscosity (v, mm²/s) was determined (triplicates, means reported) with a Cannon-Fenske viscometer (Cannon Instrument Co., State College, PA) at 40 °C in accordance with ASTM D445.[14]

2.3.5. Lubricity. Lubricity is measured as a function of wear. Lubricity data (lub, μm) were collected at 60 °C (controlled to less than ±1 °C), according to ASTM D6079[15] using a high-frequency reciprocating rig lubricity tester (PCS Instruments, London, England) via Lazar Scientific (Granger, IN). In HFRR, a ball-on-plate geometry is used as per ASTM D6079. A steel ball reciprocates back and forth on a stationary flat steel disc with constant stroke length distance, frequency, and normal force. The test oil sample is applied between the ball and the disc. After the test completion, the wear scar is measured on the steel ball using a microscope and reported in microns. The reported wear is the average of the scar sizes on the disc in both directions. The smaller the wear scar, the better the lubricity of the oil. Wear scars (μm) are the average of two replicates, measuring the maximum value of the x- and y-axis of the wear scar. The average wear scar diameter was determined by calculating the average of the x- and y-axis wear scar lengths.

2.3.6. Thermogravimetric Analysis (TGA). A TA Instruments (New Castle, DE) Q500 thermogravimeter with an autosampler was used to measure the weight loss of samples under a flowing nitrogen atmosphere. Generally, 20 mg of the sample was loaded into each platinum pan used in the TGA furnace. The samples were heated from 30 to 600 °C at a heating rate of 10 °C/min, and the weight loss was recorded as a function of temperature.

2.3.7. Pressure Differential Scanning Calorimetry (PDSC). DSC thermograms of the test samples were recorded using a TA Instruments Q20 (New Castle, DE). Typically, about 10 mg of the sample was accurately weighed into an aluminum pan and sealed with pin-perforated lids. The sample pan was

Table 2. Acid Value (AV), Cloud Point (CP), Pour Point (PP), Cold Filter Plugging Point (CFPP), Kinematic Viscosity (v), and Lubricity of ULSD Blended with TGGMO[a]

vol %	AV (mg/g)	CP (°C)	PP (°C)	CFPP (°C)	v (mm²/s)	lub (μm)	film (%)
GMO							
ULSD	0.05 (0.04)	−15 (1)	−24 (1)	−17 (1)	2.23 (0)	493 (14)	17 (0)
0.01	0.02 (0.02)	−14 (0)	−27 (1)	−17 (0)	2.19 (0)	248 (0)	85 (0)
0.02	0.03 (0.04)	−14 (1)	−27 (0)	−17 (0)	2.20 (0)	243 (11)	86 (1)
0.03	0.06 (0.03)	−14 (1)	−27 (1)	−16 (0)	2.25 (0)	232 (10)	87 (1)
0.05	0.04 (0.04)	−14 (1)	−28 (1)	−16 (0)	2.23 (0.01)	212 (8)	91 (1)
0.1	0.04 (0.02)	−14 (1)	−31 (1)	−15 (1)	2.23 (0)	187 (0)	97 (1)
0.2	0.05 (0.04)	−15 (1)	−32 (1)	−15 (1)	2.29 (0.01)	134 (8)	98 (1)
0.3	0.02 (0.06)	−15 (1)	−33 (1)	−16 (1)	2.21 (0.01)	133 (17)	98 (0)
0.4	0.03 (0.06)	−15 (1)	−33 (1)	−16 (1)	2.15 (0.01)	114 (2)	98 (0)
0.5	0.06 (0.02)	−16 (1)	−34 (1)	−15 (0)	2.26 (0)	97 (7)	99 (0)
1.0	0.12 (0.05)	−15 (1)	−36 (1)	−15 (1)	2.27 (0.01)	90 (1)	99 (0)
2.0	0.15 (0.03)	−16 (1)	−44 (1)	−16 (0)	2.37 (0.01)	103 (5)	98 (1)
5.0	0.07 (0.04)	−17 (1)	−48 (1)	−16 (1)	2.64 (0.01)	187 (5)	84 (1)
7.5	0.07 (0.04)	−17 (1)	−33 (1)	−18 (1)	2.74(0.01)	206 (2)	72 (0)
10.0	0.11 (0.03)	−16 (1)	−21 (1)	−18 (1)	2.92 (0.01)	219 (6)	69 (1)
15.0	0.1 (0.03)	−16 (1)	−19 (0)	−18 (1)	3.69 (0.01)	233 (7)	65 (1)
20.0	0.08 (0.040)	−16 (1)	−18 (0)	−17 (1)	4.29 (0)	235 (3)	60 (1)
TGGMO							
100	0.24 (0.02)	4 (2)	−2 (1)	nd[bb]	69.74 (0.01)	149 (1)	82 (0.01)

[a]The number in parenthesis represents the standard deviation (n = 3; n = 2 for lub). [b]nd = not determined due to the semisolid nature of TGGMO.

Table 3. Acid Value (AV), Free Fatty Acid (FFA), Cloud Point (CP), Pour Point (PP), Cold Filter Plugging Point (CFPP), Kinematic Viscosity (v), and Lubricity of ULSD[aa] Blended with Pure-Grade Monooleate (PGMO) and Technical-Grade Glycerol Monooleate (TGGMO)

vol %	AV (mg/g)	FFA (mg/g)	CP (°C)	PP (°C)	CFPP (°C)	v (mm²/s)	lub (μm)	film (%)
ULSD-neat	0.05	nd[bb]	−8.60	−11.00	−10.0	2.5501	249	91
							250	92
1PGMO	0.0590	0.0297	−7.37	−13.33	−9.0	2.5480	148	99
							145	99
0.5PGMO	0.0765	0.0385	−7.25	−14.33	−9.0	2.5546	142	99
							141	99
1TGGMO	0.0559	0.0281	−7.30	−15.33	−10.0	2.5885	151	99
							148	99
0.5TGGMO	0.0863	0.0434	−8.30	−12.33	−9.0	2.4731	153	99
							148	99
EN-590	0.5 max					2.0−4.5	460 max	
ASTM D-975						1.9−4.1	520 max	
TGGMO	0.1838	0.0924	nd[cc]	nd[cc]	nd[cc]	51.2626	84	92
							84	92
PGMO	1.7129	0.8610	nd[dd]	nd[dd]	nd[dd]	nd[dd]	nd[dd]	nd[dd]

[a]Different batch of ULSD used in this experiment. [b]nd = not determined. [c]nd = not determined due to the semisolid nature of TGGMO. [d]nd = not determined due to the semisolid as well as expensive nature due to 99.98% purity of PGMO.

loaded into the PDSC cell, which was sealed and charged with dry air at 1379 kPa. Data were collected, while the cell temperature was increased from room temperature to 300 °C at a rate of 5 °C/min. Thermal Advantage and Universal Analysis software provided by TA instruments (New Castle, DE) was used for data analysis.

3. RESULTS AND DISCUSSION

3.1. Fuel Properties of ULSD Blended with TGGMO/PGMO. *3.1.1. Acid Value (AV).* ULSD and TGGMO show AVs of 0.05 and 0.24 mg/g, respectively (Table 2). Overall, as shown in Table 2, not much change in the AV was observed with the addition of TGGMO to ULSD. Table 2 also displays that addition of 0.4% TGGMO gives AV less or equal to the ULSD baseline apart from 0.03%. With 0.5% TGGMO, it increases with a zigzag-type trend in the AV. In Table 2, its AV reaches a maximum of 0.11 mg/g at the 10.0% of TGGMO and then decreases slightly to 0.08 mg/g at 20.0% of TGGMO. The increase in the AV of higher concentration ULSD:TGGMO blends can be attributed to the increase in the higher concentration of TGGMO itself, for which AV is found to be 0.24 mg of KOH/g.

ULSD and PGMO show AVs of 0.05 and 1.729 mg/g, respectively (Table 3). PGMO has a 1.729 mg/g higher AV due to the presence of free fatty acids (FFA). Table 3 shows that there has not been much change in the AV after adding PGMO to ULSD. The lowest AV obtained by adding 1% TGGMO to ULSD gave an AV of 0.056 mg/g. Table 3 also reveals that adding 1% TGGMO to ULSD has the least amount of FFA.

The European diesel standard (EN 590) specifies a maximum AV of 0.5 mg KOH/g (Table 1). A satisfactory AV (<0.5 mg KOH/g) was found in all samples shown in Tables 2 and 3, whereas ASTM D6715 does not specify such a requirement.

3.1.2. Cloud Point (CP). As shown in Table 2, ULSD and TGGMO show cloud point (CP) values of −15 and 4 °C, respectively. Overall, in Table 2, not much change in the CP value was observed after addition of TGGMO. However, as the best-case scenario, with a lower amount of GMO (even better than the baseline with the addition of 0.5% TGGMO to ULSD), the CP value is −16 °C. These trends continue with the addition of a higher amount of TGGMO (up to 20%) into the ULSD, where CP value reaches a maximum of −17 °C.

Table 3 shows a CP value of −8.6 °C in ULSD, whereas PGMO and TGGMO values were not evaluated due to their semisolid nature. Table 3 also shows that the CP value did not change significantly in the blend solution of ULSD and PGMO/TGGMO. A blend with ULSD containing a lower amount (0.5%) of TGGMO produced the lowest CP value. This blend has a CP value of −8.3 °C. The current observation is consistent with the results of the previous study in Table 2.

It is important to note that the American diesel standard, ASTM D975-07b, only requires the reporting of CP, whereas the EN 590 standard does not demand such reporting (Table 1).

3.1.3. Pour Point (PP). Table 2 shows that the most enhanced fuel property of ULSD by addition of TGGMO is PP. As shown in Table 2, ULSD and TGGMO show PP values of −24 and −2 °C, respectively. With the smallest concentration (0.01%) of TGGMO, it displays a better PP than that of the baseline ULSD. These trends continue with addition of 5.0% TGGMO, reaching its lowest PP (−48 °C). To see the impact of the addition of a higher amount of TGGMO, studies were conducted with the addition of 20% TGGMO. However, the PP was reduced drastically to −21, −19, and −18 °C for 10, 15, and 20%, respectively, by addition of TGGMO to ULSD, which is even lower than the baseline. It is interesting to note that the PP was significantly influenced by the addition of TGGMO, even though the GMO PP is only −2 °C. It is also interesting to note that PP properties of the ULSD have been impacted by the addition of TGGMO. With the addition of 5% TGGMO to ULSD, the PP increased to double that of ULSD. This fuel property can be explored by the manufacturer to design ULSD with the lowest PP to use in very cold regions of the world.

Table 3 shows the PP value of ULSD at −11.0 °C, whereas PGMO and TGGMO were not evaluated due to their semisolid nature. It is evident in Table 3 that the PP value changed significantly in the blend solution between ULSD and PGMO/TGGMO. Blends containing 1.0% TGGMO in ULSD produced the lowest PP value compared to blends with 1.0% PGMO. The PP values of both blends mentioned above are −15.3 and −13.3 °C, respectively. Based on data from the previous study, Table 2 shows that the current findings are similar.

3.1.4. Cold Filter Plugging Point (CFPP). As shown in Table 2, ULSD shows CFPP values of −17 °C, while the CFPP value of TGGMO was not determined due to the semisolid nature of GMO. Overall, Table 2 shows that not much change occurred in the CFPP value after addition of TGGMO was observed. However, as the best-case scenario, with the smallest addition of 0.01% TGGMO to ULSD, the CFPP value is −17 °C.

The influence of TGGMO addition on the CFPP (Table 2) was the same for all ULSD blends, since all samples displayed reductions of 1−2 °C versus their initial CFPP values.

As shown in Table 3, ULSDs show CFPP values of −10 °C, while PGMO/TGGMO was not evaluated due to the semisolid nature. Overall, Table 3 indicates that CFPP values have not significantly changed after adding PGMO/TGGMO. Adding 1% TGGMO to ULSD, however, achieves the best CFPP value of −10 °C, which is the same as the CFPP value of ULSD.

Unlike CP and PP, CFPP did not appear to be influenced by the initial CFPP value of ULSD. No positive change was observed with the addition of TGGMO and PGMO in ULSD, and it also did not negatively affect the CFPP.

It is only required to report the CFPP, depending on the location and time of the year, according to the American diesel standards ASTM D975-07b and EN 590.

3.1.5. Viscosity. ULSD and TGGMO show a viscosity of 2.23 and 69.74 mm^2/s at 40 °C, respectively (Table 2). Overall, not much change in viscosity was observed after the addition of TGGMO to ULSD. Addition of 0.5% TGGMO on the viscosity value shows a small increasing trend.

As shown in Table 2, kinematic viscosity increases as the percentage of TGGMO was increased, reaching a maximum value of 4.29 mm^2/s at 20.0% of TGGMO. This is because TGGMO had higher kinematic viscosity (69.74 mm^2/s; 40 °C) than that of ULSD.

As shown in Table 3, ULSD and TGGMO show a viscosity of 2.55 and 51.26 mm^2/s at 40 °C, respectively. At 0.5 and 1% TGGMO and PGMO, not much change was observed in the viscosity of ULSD blends.

The viscosities of all samples shown in Tables 2 and 3 meet the specifications of the ASTM standard D975-07b (1.3−2.4 mm^2/s) or are close to the upper limit of the specification.

3.1.6. Lubricity. ULSD and TGGMO show a lubricity of 493 and 149 μm, respectively (Table 2).

With the least concentration (0.01%) of TGGMO, the blend displayed better lubricity than that of the baseline ULSD. These trends continue until addition of 1.0% TGGMO where lubricity reaches the lowest wear scar of 90 μm. This fuel property has been explored by the manufacturers to design ULSD with the lowest lubricity to compensate for the decrease in lubricity due to the removal of more sulfur. To see the impact of addition of a higher amount of TGGMO to ULSD, studies were conducted until the addition of 20% TGGMO. However, lubricity again increases slightly for 2.0% TGGMO to 103 μm. Further addition of 5, 7.5, 10, 15, and 20% TGGMO in ULSD steadily increased the lubricity; however, it is still half that of the baseline ULSD lubricity.

Since the best results in lubricity reductions were obtained with the addition of 0.5 and 1% TGGMO, for comparison purposes, 0.5 and 1% blends of TGGMO and PGMO were prepared. As PGMO is semisolid and expensive, its lubricity was not measured. After adding both TGGMO and PGMO,

the lubricity of ULSD significantly changed from an initial wear scar value of 250 to 141−153 μm.

The lubricity of all samples shown in Tables 2 and 3 was well under the prescribed maximum for both ASTM D975-07b (max 520 μm) and EN 590 (max 460 μm) standard specifications.

3.1.7. Pressure Differential Scanning Calorimetry (PDSC). The pressure module was temperature-calibrated using the melting point of indium metal (156.6 °C) at 5 °C/min heating rate. The onset temperature of oxidation (OT) for each sample was calculated from the corresponding exotherm. The oxidation stability of TGGMO and PGMO is lower than that of ULSD, as shown in OT and peak maximum temperature (PM) in Table 4. TGGMO showed higher

Table 4. PDSC and TGA Data of ULSD[a][a] **Blended with Pure-Grade Monooleate (PGMO) and Technical-Grade Glycerol Monooleate (TGGMO)**

samples	PDSC		TGA	
	onset temperature (°C)	peak maxima (°C)	TGA-peak maxima (°C)	temperature at 50% loss (°C)
ULSD	191.7	204.6	165.5	139.3
TGGMO	162.1	190.9	304.7	308.9
0.5% TGGMO in ULSD	188.5	202.5	177.4	149.4
1% TGGMO in ULSD	185	199.4	178.6	148.9
PGMO	153.0	186.6	273.5	265.5
0.5% PGMO in ULSD	181.4	196.9	171.9	145
1% PGMO in ULSD	183.0	199.4	177.3	153

[a]Different batch of ULSD used in this experiment.

oxidation stability with an OT of 162 °C compared to 153 °C for PGMO. This shows that addition of TGGMO will result in less lowering of OT compared to that of PGMO, which means that the blend with TGGMO will have better oxidation stability compared to that of PGMO. For example, 0.5% addition of TGGMO resulted in lowering of the OT to 188.5 °C compared to addition of 0.5% PGMO (181.4 °C) from 191.7 °C for ULSD. Similarly, with addition of 1% additive, there was a higher decrease in OT with PGMO compared to that of TGGMO. Similar trends were obtained using PM data. Among different blends, 0.5% TGGMO shows the best oxidation stability, followed by 1% TGGMO, 0.5% PGMO, and 1% PGMO, in order. From this data, it can be concluded that although addition of up to 1% TGGMO will lower the oxidation stability slightly, it is better than addition of 1% PGMO.

3.1.8. Thermogravimetric Analysis (TGA). TGA results are compiled in Table 4. Thermal or storage stability improves with addition of TGGMO more than with addition of PGMO, which is due to the higher thermal stability of TGGMO compared to that of PGMO. This could also be due to the lesser volatility of TGGMO compared to that of PGMO. Among the various GMO blends, the peak maxima of the derivative TGA curve (TGA-PM) were higher for TGGMO compared to those of PGMO blends. Similarly, the temperature at 50% loss increased for TGGMO blends more than for the PGMO blends, which is again due to the higher thermal stability or less volatility of TGGMO compared to that of

PGMO. These results further demonstrate the advantage of using TGGMO compared to PGMO.

4. CONCLUSIONS

In summary, it is demonstrated that blending of various concentrations of TGGMO/PGMO with ULSD improved certain physical properties of ULSD such as PP and lubricity. Although the AV of the blended ULSD increased slightly, in some cases, after addition of a higher level (1−5%) of TGGMO, the CP and CFPP values of the blends were unaffected.

The study also showed that addition of TGGMO at the smallest amount (0.01%, 1000 ppm) to ULSD improved the lubricity and pour point, while not affecting other fuel properties, thereby improving the ULSD. This encourages ULSD manufacturers to use TGGMO to design fuel with a better PP and lubricity as per the needs of the coldest regions of the world. Thermal and oxidative stability studies, along with other properties, also demonstrated the advantages of using TGGMO blends compared to PGMO blends.

In summary, TGGMO has a bright prospect as a fuel additive or blend component for ULSD to improve the lubricity and PP, and it may be cheaper and facilitate better improvement in the fuel property of ULSD.

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Notes

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■ NOMENCLATURE

TLC, thin-layer chromatography; TGGMO, technical-grade glycerol monooleate; PGMO, pure-grade monooleate; AV, acid value; CFPP, cold filter plugging point; CP, cloud point; GMO, glycerol mono oleate; FA, fatty acid; FFA, free fatty acid; FAME, fatty acid methyl ester; PP, pour point; ULSD, ultralow-sulfur diesel fuel

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