



## Research Paper

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# Effect of blending of biofuels with ultralow sulfur diesel on diesel engine's exhaust emissions

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### ABSTRACT

The use of biofuel as a supplementary fuel may reduce environmental pollution, strengthen the agricultural economy, create job opportunities and reduce diesel requirements, thereby contributing to the conservation of a major commercial energy source. Methanol is one of the possible alternatives for the partial replacement of mineral diesel in diesel engines. The studies apply biofuel (methanol) blends on the engine exhaust emissions results were compared with the baseline (pure ultralow sulfur diesel fuel) case. Results showed that the CO emissions could be reduced by up to 33.33% for the 5 wt% methanol blend case, HC emissions could be reduced by up to 20.83%, NO<sub>x</sub> emissions could be reduced by up to 25.38%, smoke emissions could be reduced by up to 13.19%, CO<sub>2</sub> emissions could be reduced by up to 16.13%, engine exhaust gas temperatures could be decreased by 5.56%; and O<sub>2</sub> emission could be increased by 1.89%. Thus, biofuel (methanol) blends can be added to diesel fuel for reducing engine exhaust emissions. The engine exhaust emissions for biofuel (methanol) blends are lower than those for pure ultralow sulfur diesel fuel because of the presence of O<sub>2</sub> in the molecular structure of the biofuel (methanol). Biofuel is increasingly replacing pure ultralow sulfur diesel fuel as a renewable and sustainable alternative for diesel engines.

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### INTRODUCTION

Recent concerns over the environmental impact of diesel-powered machinery have driven various countries to legislate to achieve a reduction in vehicle exhaust emission levels and change existing fuel quality standards. To meet the requirements of reduced exhaust emissions, automakers have begun exploring the use of alternative fuels such as biofuel. Apart from reduced emissions, benefits of biofuel include increased employment and improved economic conditions, especially in rural areas, enhanced energy security because of reduced dependence on oil imports, foreign exchange savings and practically zero contribution to global warming (Sulek et al., 2010; Haseeb et al., 2011; Masjuki and Maleque, 1997). Although the consumption of biofuel is relatively low compared with that of conventional energy sources, the scenario is rapidly

changing. When factors are coupled with vast agri-resources, new technologies that reduce biofuel cost, emphasis on environmental protection and pollution abatement and strong will from both the government and private entrepreneurs, the market for biofuels is expected to slowly but surely increase (Atadashi et al., 2010; www.science.gov; Dwivedi et al., 2006). One strategy for meeting emission regulations and achieving a reduction in CO<sub>2</sub> from transportation is to use cleaner fuels. Bio-derived methanol fuels are potential alternatives both as a renewable energy source and for helping the transport sector meet bioenergy consumption targets (Hamamci et al., 2011; Liaquat et al., 2010; Michel and Boris, 2009; Kalam et al., 2011; Savita et al., 2007). Many researchers have tested the use of different proportions of biodiesel, as

listed in petroleum fuel emissions, in diesel engines for minimizing the resulting adverse effects on nature. For example an uncontrolled CO<sub>2</sub> increase results in an increase (global warming) or decrease in the global temperature (global cooling) (Kalam et al., 2003; Ong et al., 2011).

Using methanol as a diesel engine fuel is highly beneficial because toxic emissions are drastically reduced. Although methanol-based fuels have been traditionally used in spark ignition (SI) engines, they have also been considered for use in compression ignition (CI) engines. Other benefits of using these fuels include reductions in CO emission, smoke opacity and particulate matter emissions. These emission benefits, resulting from the effect of oxygen in the hydroxyl group, have increased interest in the use of methanol blended with conventional diesel in CI engines (Atabani et al., 2012; Issariyakul et al., 2007). Methanol can be successfully used in diesel engines, either directly or as biodiesel. The formation of hydrogen bridges in methanol molecules results in the higher boiling point of methanol in comparison to gasoline. Therefore, methanol has high storage stability. Furthermore, methanol is less toxic than gasoline, another methanol used as fuel and the high octane number of methanol facilitates higher compression ratios compared with those of gasoline-fuelled engines (Braun and Pachauri, 2006; Zhou and Thomson, 2009; Jinlin et al., 2011; Costa and Sodr , 2010). Methanol is alternative transportation fuels because of their properties, which are favorable for its use in existing engines with minor hardware modifications. They also have a higher octane number than gasoline. The use of methanol as a fuel additive for gasoline leads to the enhancement of engine performance and a reduction in exhaust emissions. However, the brake specific fuel consumption and equivalence air–fuel ratio decrease because of the lower calorific value of gasohol.

The use of blends with a high percentage of methanol is limited because of their poor miscibility with conventional diesel, low cetane number, low energy density, low viscosity, low lubricity and high volatility (Liaquat et al., 2012). The American Society for Testing and Materials developed E85 (85% ethanol and 15% gasoline) fuel specifications for automotive SI engines and these specifications were prescribed by the Renewable Fuels Association (2005). Both methanol and biodiesel contain oxygen and their use leads to reduced exhaust emissions of many pollutants. In terms of CO and soot emissions, for combustion, the use of methanol blends is more beneficial than are biodiesel blends with the same oxygen content. Short carbon chain lengths and saturated methyl esters are recommended for improving biodiesel blends. Natural gas, hydrogen, vegetable oil, alcohol and biogas are among the most promising alternative fuels. The use of biofuels and alcohols in diesel fuels as a blend has been intensively researched over the past couple of decades. Both ethanol and biodiesel contain oxygen and their use leads to reduced

exhaust emissions of many harmful pollutants. According to Agarwal (2007), the brake torque and volumetric efficiency increase and the antiknock behavior improves with an increase in the methanol content of methanol–diesel fuel blends. Abu-Qudais et al (2000) found that the optimal amount of ethanol that should be added to diesel is approximately 15–20%. The author observed that while the brake thermal efficiency (BTE) increased by 7.5% upon the addition of 20% ethanol as a fumigant, smoke emission and the soot mass concentration decreased by 48% and 51%, respectively. Moreover, while BTE increased by 3.6% upon the addition of 15% ethanol to diesel, fuel smoke emission and soot mass concentration decreased by 33.3% and 32.5% respectively.

Buyukkaya (2010) observed that the smoke opacity reduction was 45% for B70, whereas it was 60% for pure biodiesel. The author also found that the brake specific fuel consumption of the B5, B20, B70, and B100 fuels was higher by 2.5%, 3%, 5.5%, and 7.5% compared with that of diesel, respectively. Furthermore, except for B70, the BTE of the engine increased with the concentration of the biodiesel in the blend (Suryawanshi and Deshpande, 2004; Gokalp et al., 2011). For combustion, the use of methanol blends is clearly beneficial compared with diesel blends with the same oxygen content in terms of smoke and NO<sub>x</sub> emissions. Emission benefits have led to increased interest in the use of methanol blended with conventional diesel in CI engines. In the current study, the effect on the combustion characteristics of diesel engines and emissions of specific methanol was assessed.

## **EXPERIMENTAL PROCEDURE**

The study was comparison of 5 wt.% biofuel(methanol) blends and pure ultralow sulfur diesel in terms of engine exhaust emitted by a diesel engine. The water-cooled diesel engine used in the engine test had a 4-cylinder four-stroke engine with direct injection (Figure 1). The engine specifications are listed in Table 1. Methanol and pure ultralow sulfur diesel were blended at the aforementioned concentrations in a container by using a centrifugal machine at room temperature for 24 h to ensure homogeneity. The essential fuel properties are listed in Table 2. Stability tests were performed for each blend to determine whether phase separation occurred. To evaluate the emission characteristics, a portable SINCRO exhaust gas analyzer was used to measure the concentrations of gases in the exhaust of the test engine, such as NO<sub>x</sub> (ppm), HC (ppm), CO(%vol.), CO<sub>2</sub>(%vol.), O<sub>2</sub>(%vol.), Smoke (%vol.) and the exhaust gas temperature (°C). The test conditions conformed to those specified in the ISO standard for testing emission characteristics. A fuel temperature of 40°C, relative humidity of 50–55% and a mean ambient temperature (in the laboratory) of approximately 25°C were maintained during the tests.



**Figure 1:** Experimental set-up of the diesel engine testing system.

**Table 1:** Test engine specifications.

Item	Specifications
Engine	Diesel engine
Engine Category	Four strokes, water-cooled
Engine Type	TRAJET 2.0, TCI
Bore x stroke	83 x 92 mm
Displacement	1991 cc
Cylinders	In-line 4 Cylinder
Compression Ratio	17.7 : 1
Fuel System	Common Rail (Direct Injection)
<b>Injection Pressure</b>	
Nozzle	1500 bar max
Air Intake System	Hole
Emission Control System	Turbocharged with inter cooler DOC, PCV, EGR

**Table 2:** Base fuel properties

Property	Diesel	Methanol
Chemical formula	C <sub>16</sub> H <sub>34</sub>	CH <sub>3</sub> OH
Molar mass (g·mol <sup>-1</sup> )	226.4412	32.04
Density (g/cm <sup>3</sup> )	0.82~0.845	0.7918
Viscosity (20°C, Cst)	2.62	0.59
Flash point (°C)	40	11
Melting point(°C)	-29.56	-97
Boiling point(°C)	170~390	64.7



**Figure 2:** Sedimentation of methanol in (a) pure ultralow sulfur diesel, and pure ultralow sulfur diesel blended with (b) 1 wt.% methanol, (c) 2 wt.% methanol, and (d) 5 wt.% methanol.

## RESULTS AND DISCUSSION

The study was performed in the following two steps.

### Blend stability

The experiment was performed using 1-5 wt.% methanol in pure ultralow sulfur diesel fuel. The blended fuel was maintained at 25–30°C and its stability was tested every 2 h for the first 24 h and every day thereafter for a month. During this test period, no precipitation or phase separation, indicators of changes in the stability and miscibility of the two fuels was observed (Figure 2).

### Engine performance test

A fuel injection pump served as a highly efficient mechanical stirrer for blending the biofuel. The engines operated smoothly with no initial starting problems or engine knocking. A visual inspection of the injector nozzles of each fuel system at the end of each test revealed no major carbon deposits on the nozzle tips. Pollutants from diesel engines include CO, HC, CO<sub>2</sub>, NO<sub>x</sub> and smoke. Most diesel engines run exclusively on lean mixtures, such as 14:1 time of stoichiometric air-fuel ratio. Therefore, the CO emission is typically lower than that of gasoline engines. CO exhaust emissions for various types of fuel at engine speeds in the range 1000–3000 rpm are shown in Figure 3 and the emissions for pure ultralow sulfur diesel and 5 wt% methanol blends at 2000 rpm were 0.090% and 0.081%, respectively. High structural oxygen content of a biofuel (methanol) enhances the combustion efficiency of the biofuel because of an increase in the homogeneity of oxygen in the fuel during combustion. Therefore, the combustion efficiency of biofuel blends is higher than that of pure

ultralow sulfur diesel fuel. Therefore, the CO emission for 5 wt.% methanol blends is typically lower than that for pure ultralow sulfur diesel. Hydrocarbon (HC) exhaust emissions of diesel engines result from incomplete fuel combustion because of flame quenching in crevice regions in the cylinder wall. A comparison of unburned HC exhaust emissions of various fuels at engine speeds of 1000–3000 rpm is shown in Figure 4. The HC exhaust emissions for pure ultralow sulfur diesel and 5 wt.% methanol blends at 3000 rpm were 48 and 38 ppm respectively. Suryawanshi and Deshpande (2004) reported that HC exhaust emissions for biofuel blends were significantly lower than those for pure ultralow sulfur diesel.

The HC exhaust emissions for a biofuel blend can be reduced further by increasing the biofuel content. In fact, in engines operated with biofuel, unburned HC can be reduced by 53%. A comparison of CO<sub>2</sub> exhaust emissions of various fuels at engine speeds of 1000–3000 rpm is shown in Figure 5. The maximum CO<sub>2</sub> exhaust emission corresponded to pure ultralow sulfur diesel and resulted from increased combustion under the throttle speed-engine operation conditions. O<sub>2</sub> exhaust emissions from a diesel engine for various fuels are shown in Figure 6. The emissions for pure ultralow sulfur diesel and 5 wt.% methanol blends at 2000 rpm were 16.94% and 17.26% respectively. The 5 wt.% methanol blends showed higher O<sub>2</sub> exhaust emission concentrations because they contained a higher amount of O<sub>2</sub> than pure ultralow sulfur diesel did. Compared with pure ultralow sulfur diesel, the NO<sub>x</sub> exhaust emissions of 5 wt.% methanol blends were lower by 25.38% (Figure 7). The difference was primarily because of the decrease in the combustion temperature of the 5 wt.% methanol blend fuels, which can be attributed to methanol blend fuels having a lower heat release rate in the premix combustion phase. The lower heat release rate reduces the peak combustion temperature and decreases NO<sub>x</sub> emissions. Figure 7 shows that the use of hot exhaust

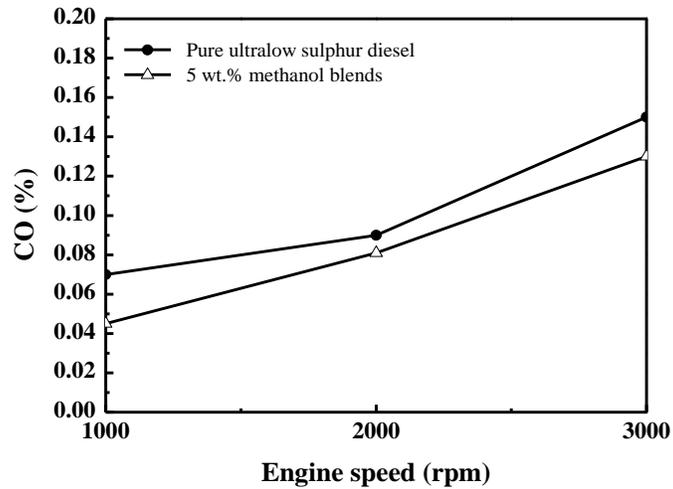


Figure 3: CO exhaust emissions for various types of fuels.

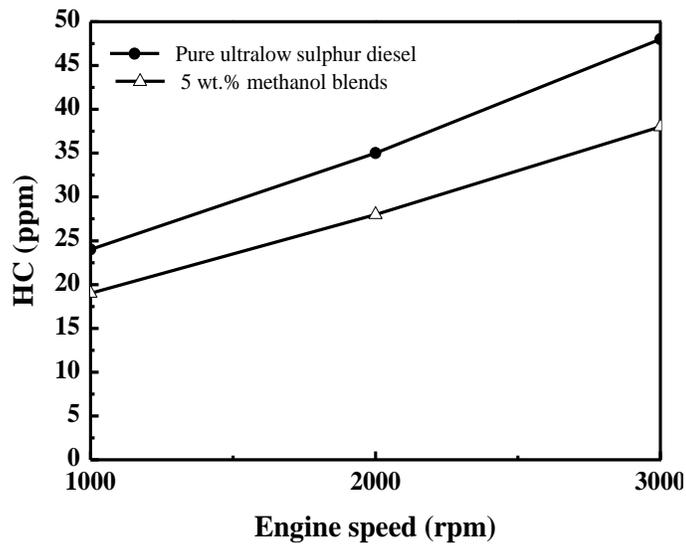


Figure 4: HC exhaust emissions for various types of fuel.

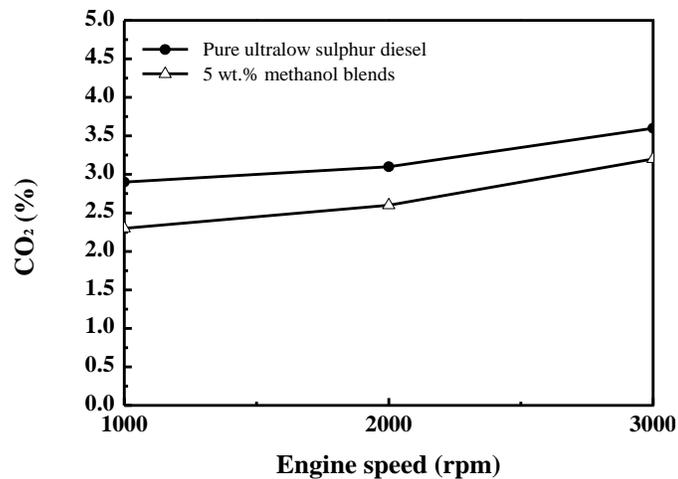


Figure 5: CO<sub>2</sub> exhaust emissions for various types of fuel.

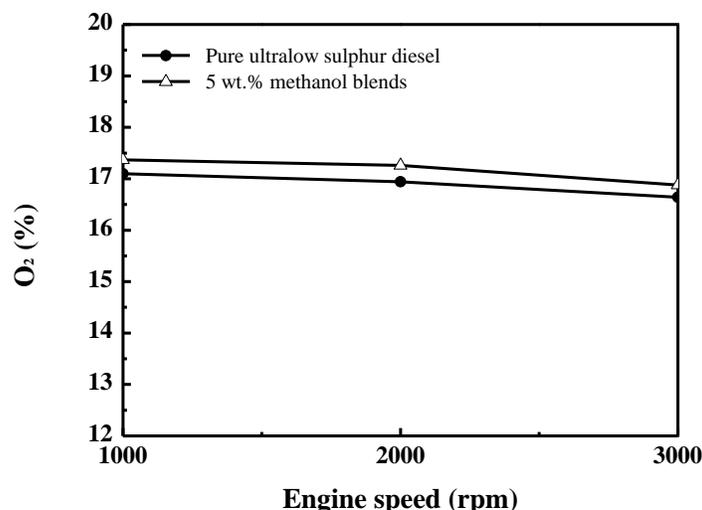


Figure 6: Oxygen emissions for various types of fuel.

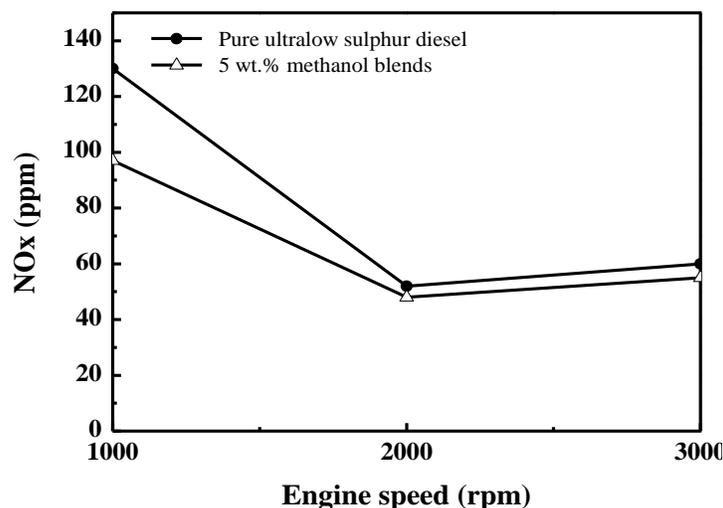


Figure 7: NO x emissions for various types of fuel.

gas recirculation (2000 rpm) for controlling NO<sub>x</sub> in diesel engines fuelled by biofuel can effectively reduce NO<sub>x</sub> emission, thereby reducing the peak combustion temperature and hence NO<sub>x</sub> emissions.

The 5 wt% methanol blends showed a lower smoke emission level compared with pure ultralow sulfur diesel (Figure 8). The ignition delay for 5 wt% methanol blend oil was shorter than that for pure ultralow sulfur diesel, which influenced smoke emission. The lowest smoke emission was observed for the 5 wt% methanol blend oil at 1000–3000 rpm. This implied that the 5 wt% methanol blend oil underwent a more complete combustion than did pure ultralow sulfur diesel. On average, the smoke opacity for the 5 wt% methanol blend oil was 13.19% lesser than that for pure ultralow sulfur diesel. Because biofuel is free from sulfur, reduced sulfate and particulate emissions in the

exhaust was observed. The variation in the exhaust gas temperature for all the tested fuels is shown in Figure 9. The lowest level of exhaust gas temperature was observed for the 5 wt.% methanol blends and it was followed by pure ultralow sulfur diesel. The exhaust temperature for the 5 wt.% methanol blend fuels varied between 188°C to 324°C at 1000–3000rpm, whereas the variation was in the range 204°C to 337°C for the same speed range for pure ultralow sulfur diesel, indicating limited variation; this could be due to the same consumption rate of fuel for the diesel and biofuels blends. Compared with pure ultralow sulfur diesel fuel, the 5 wt.% methanol blends showed superior combustion characteristics. For example, when the 5 wt.% methanol blends were used as engine fuel, their oxygen content (approximately 10 wt%) may facilitate more complete combustion and effectively reduce the production

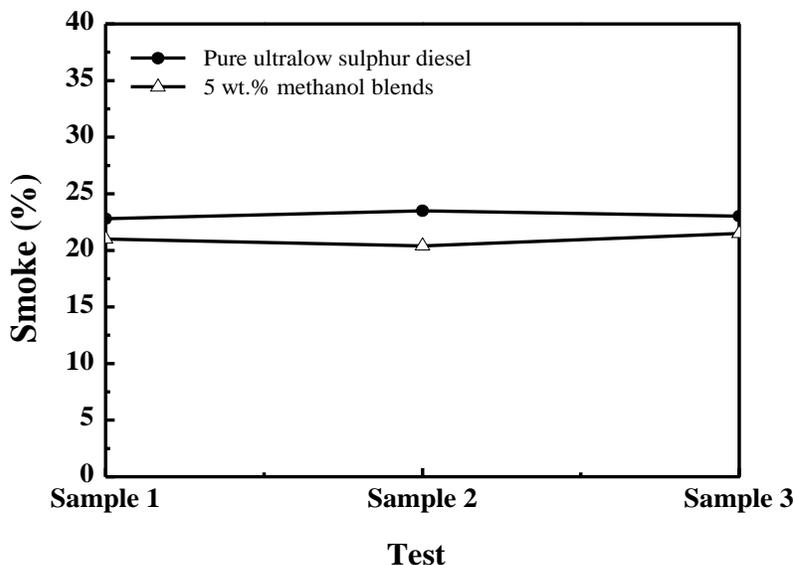


Figure 8: Smoke emissions for various types of fuel.

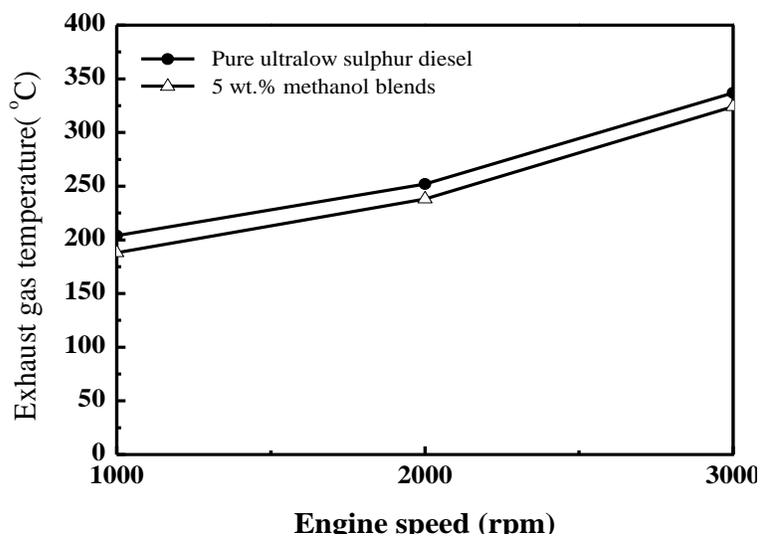


Figure 9: Exhaust gas temperatures for various types of fuel.

of HC, CO, CO<sub>2</sub>, NO<sub>x</sub>, and suspended aerosol carbon granules (smoke). The oxygen concentration of biofuel is very high and their combustion is more complete. Therefore, the combustion efficiency of biofuel is high. The experimental results suggest that adding biofuel (methanol) to pure ultralow sulfur diesel fuel helps decrease engine exhaust emissions which are human health hazards.

## CONCLUSIONS

The studies apply biofuel (methanol) blends on the engine exhaust emissions results were compared with the baseline

(pure ultralow sulfur diesel fuel) case. Results showed that the CO emissions could be reduced by up to 33.33% for the 5 wt.% methanol blend case, HC emissions could be reduced by up to 20.83%, NO<sub>x</sub> emissions could be reduced by up to 25.38%, smoke emissions could be reduced by up to 13.19%, CO<sub>2</sub> emissions could be reduced by up to 16.13%, engine exhaust gas temperatures could be decreased by 5.56%; and O<sub>2</sub> emission could be increased by 1.89%. Thus, biofuel (methanol) blends can be added to diesel fuel for reducing engine exhaust emissions. The engine exhaust emissions for biofuel (methanol) blends are lower than those for pure ultralow sulfur diesel fuel because of the presence of O<sub>2</sub> in the molecular structure of the biofuel. Biofuel is increasingly replacing pure ultralow

sulfur diesel fuel as a renewable and sustainable alternative for CI engines.

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