Comparison of the Engine Performance and Emissions Characteristics of Vegetable Oil-Based and Animal Fat-Based Biodiesel

Jon Van Gerpen
Iowa State University

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Introduction

Biodiesel fuels produced from animal fats and vegetable oils have similar composition. The primary difference is that the animal fat-based biodiesel contains more saturated fatty esters. Soybean oil is typically about 12-15% saturated while tallow is typically about 50% saturated. This greater saturation raises the cloud point of animal-fat based biodiesel but appears to have little effect on the combustion and exhaust emissions characteristics of the fuel.

These comments are intended as a response to the Environmental Protection Agency's request for public comment on the proposed rule change to permit animal- and vegetable-derived biodiesel fuels to be grouped together. The discussion provided in this document supports the grouping of these fuels based on their similar engine performance and emissions characteristics.

Emissions comparison of animal- and vegetable-based biodiesel

Marshall [1,2] has tested a 1992 Cummins L 1 OE engine with blends of both vegetable oil-based biodiesel and animal fat-based biodiesel as neat fuels and as blends with No. 2 diesel fuel. These biodiesel fuels were produced by transesterifying soybean oil and beef tallow and were identified as soy methyl ester (SME) and tallow methyl ester (TME). Marshall used a simulation of the EPA heavy duty transient test based on selected steady-state operating points. Table 1 shows a summary of the regulated emissions for the fuels. The actual pollutant emission is shown on a brake specific basis with the change from the baseline diesel fuel shown in parentheses. The reductions in unburned hydrocarbons (HC) are 12.5% for the 20% SME blend and 58.3% for the neat SME. These reductions are somewhat greater than the 8.3% reduction for the 20% TME and the 37.5% reduction for the neat TME. While these differences may be attributable to the higher soluble organic

Table 1. Simulated transient emissions for SME and TME [1,2].

	Emissions - g/hp-hr			
Fuel	HC	c o	NOx	Part
Low sulfur 2D	0.24	1.7	6.42	0.07
20% SME	0.21 -12.5%	1.3 (-23.5%)	6.85 (+6.7%)	0.07 (0 %)
100% SME	0.10 (-58.3%)	1.0 (-41.1%)	7.39 (+15.1%)	0.04 (-42.8%)
20% TME	0.22 (-8.39'0)	1.3 (-23.5%)	6.31 (-0.1%)	0.06 (-14.3%)
1 00% TME	0.15 (-37.5%)	1.1 (-35.39'0)	7.12 (+10.9%)	0.05 (-28.6%)

fraction noted with saturated esters (described below), the variation is within the range commonly experienced with conventional diesel fuel from different sources. The reductions in carbon monoxide (CO) are very similar for the two fuels. Both SME and TME gave 23.5% reductions when 20% blends were used and the neat fuels gave 35 to 4 1% reductions.

The 20% SME blend gave 6.7% higher oxides of nitrogen (NOx) while the 20% TME blend showed no change in NOx. When the neat fuels were used, the NOx increased between 10 and 15%. The particulate emissions also show similarities although the particulate levels are already very low. Marshall [1] notes that there is considerable question about whether transient cycle particulates can be accurately simulated with steady state testing.

The Cummms engine used for comparing SME and TME was later tested with SME only over the EPA heavy-duty transient cycle [3]. The transient test results are shown in Table 2. The reductions are similar to those observed with the simulated transient test. This indicates that the simulated transient results are credible.

Table 2. Results of EPA heavy duty transient testing on Cummins L10E engine.

	Emissions - g/hp-hr			
Fuel	HC	c o	NOx	Part
Low sulfur 2D	0.27	1.46	5.01	0.105
20% SME	0.25 (-7.4%)	1.22 (-16.4%)	5.17 (+3.2%)	0.092 (-12.4%)

Investigations with pure esters

To further investigate the effect of biodiesel composition, Schmidt and Van Gerpen [4] ran blends of the various pure esters found in SME and TME with No. 2 low sulfur diesel fuel. These tests were conducted in a John Deere 4276T. This is a four-cylinder, four-stroke, turbocharged diesel engine. Five different esters were blended at 20% and 50% levels with No. 2 diesel fuel. Methyl palmitate and methyl stearate, the two principal saturated esters found in both vegetable oil-based biodiesel and animal fat-based biodiesel, were available in 97+ % purity. Methyl oleate was purchased as a free fatty acid and esterified to produce a 92% pure sample. A high linoleic (77 %) safflower oil was used to produce methyl linoleate and linseed oil was used to produce an ester containing 56% methyl linolenate. These tests tend to exaggerate the effect of fuel composition changes since the differences between soybean oil and tallow are not as extreme as between the fuel samples described here.

Performance testing showed that while the power decreased and the brake specific fuel consumption increased for all of the fuel samples, compared with No. 2 diesel fuel, the amount of the changes were in direct proportion to the lower energy content of the biodiesel. Calculations of the fuel conversion efficiency, based on the lower heating value of the fuel, showed that all of the fuels had the same efficiency. This indicates that regardless of the degree of saturation of the ester, there are no fundamental changes in the way the different esters burn in the engine.

Emissions testing showed similar results. Carbon monoxide and unburned hydrocarbons decreased as the ester blend level was increased. Oxides of nitrogen increased slightly although the increase was not statistically significant. Moreover, the differences between the esters and diesel fuel were generally far greater than the differences between the esters themselves. There were some differences noted in the particulate emissions. While the particulate emissions generally decreased as the ester blend level increased, the carbon fraction of the particulate decreased by a larger fraction. The greatest reduction in carbon fraction was for methyl palmitate, an ester that composes about 8% of SME and about 28% of TME. The decrease in the carbon fraction was partially offset by an increase in the soluble organic &action. While this effect was uniformly observed for all of the esters, the increase in soluble fraction was larger for the saturated esters. The effect of ester composition on the increase of the soluble organic fraction is currently being investigated by the National Biodiesel Board. However, McDonald, et al. [5] has shown that most of the increase in soluble organic fraction observed with biodiesel is unburned esters and that it is easily reduced with an oxidation catalytic converter.

Conclusions

Biodiesel fuels produced from vegetable oils and animal fats are very similar. They contain the same chemical compounds but in different amounts. The fuels respond in a similar manner when burned in a diesel *engine,* Both fuels reduce unburned hydrocarbons, carbon monoxide, and particulates and both cause slight increases in oxides of nitrogen. The differences in the measured values of the pollutants from the two fuels are within the range experienced with conventional diesel fuels from different refineries. There does not appear to be any basis for making a distinction between the two fuels in terms of their impact on engine performance and emissions.

References

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