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DIESEL ENGINE PERFORMANCE AND EXHAUST EMISSIONS USING COTTONSEED OIL BIODIESEL

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Abstract

Non-road diesel engines are significant contributors to air pollution in the United States (USEPA, 2004). These engines emit particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and other pollutants. The Clean Air Non-road Diesel Rule was put in place to reduce emission levels from agricultural, construction, and industrial diesel powered equipment. This rule calls for a reduction in sulfur concentrations in diesel fuel. While this reduction will decrease SO_2 emissions, it will also affect fuel lubricity since sulfur in the fuel acts as a lubricant. Biodiesel is a clean burning alternative fuel produced from plant oils or animal fats (NBB, 2006a). Biodiesel is easily blended with petroleum diesel to create biodiesel blends, and is essentially free of sulfur. Biodiesel blends, which contain less sulfur than petroleum diesel, decrease the concentration of sulfur in the fuel, while providing engine lubrication that would otherwise be provided by the sulfur in the fuel. Biodiesel has a lower energy content than petroleum diesel. Therefore, biodiesel blends have a lower energy content. This difference in energy content will likely result in lower fuel efficiency for biodiesel blends. In the experiment planned for this research, brake specific fuel consumption will be determined for a 19 horsepower engine using several cottonseed oil-biodiesel blends. Engine performance curves will also be developed.

Introduction

This paper contains the research plan for testing engine performance and emissions of pollutants corresponding to the use of various fuel blends of cottonseed oil biodiesel. The plan was to include results as well. However, some equipment problems prevented the testing prior to this conference.

According to the United States Environmental Protection Agency, or EPA, (2004), non-road diesel engines are significant contributors of air pollution in the United States. Non-road diesel engines are found primarily in construction, agricultural, and industrial applications. These engines are projected to continue to contribute large quantities of pollutants that contribute to serious public health problems. The primary pollutants of interest include particulate matter (PM), nitrogen oxides (NO_x), and sulfur oxides (SO_x). Health problems associated with these pollutants include premature mortality, aggravation of respiratory and cardiovascular disease, and various other respiratory-related ailments. The EPA (2004) also believes that diesel exhaust may be carcinogenic to humans. "Ozone, NO_x, and PM also cause significant public welfare harm such as damage to crops, eutrophication, regional haze, and soiling of building materials." (USEPA, 2004). The USEPA has adopted new emissions standards for non-road diesel engines and sulfur reductions in non-road diesel fuel, effective August 30, 2004. These changes should reduce harmful emissions, as well as help states and local areas designated as 8-hour ozone non-attainment areas to improve their air quality. According to the Texas Commission on Environmental Quality, or TCEQ, (2005), ozone is not directly emitted into the air; it is formed during a series of atmospheric chemical reactions involving, sunlight, NO_x, and reactive volatile organic compounds (RVOCs).

The EPA finalized a two-step sulfur standard for non-road, locomotive, and marine (NRLM) diesel fuel. The sulfur requirements under this standard are similar to those established for highway diesel fuel. "Beginning June 1, 2007, refiners will be required to produce NRLM diesel fuel with a maximum sulfur content of 500 ppm. Then, beginning June 1, 2010, the sulfur content will be reduced for non-road diesel fuel to 15 ppm" (USEPA, 2004). This standard will achieve considerable, cost-effective reductions of sulfate PM and SO_2 emissions, which will provide substantial public health and environmental benefits which outweigh the cost of meeting the standards necessary to achieve them. The final sulfur standards will also allow high efficiency control technology to be applied to non-road engines, since sulfur can inhibit or impair the function of diesel exhaust emission control devices that will be necessary for non-road diesel engines to meet the finalized emission standards (USEPA, 2004).

Sulfur in diesel fuel also acts as an engine lubricant. This is important because reducing sulfur content reduces fuel lubricity. While newer engines may be designed to handle low sulfur fuel, older engines may not. For example, fueling an older model engine with low sulfur diesel for an extended period of time may result in injectors sticking.

According to the National Biodiesel Board, or NBB, (2006a), biodiesel is a clean burning alternative fuel produced from domestic, renewable resources, such as plant oils or animal fats. While biodiesel contains no petroleum, it can be blended with petroleum diesel to create a biodiesel blend. "Biodiesel has a slightly higher cetane number and produces less soot and polycyclic aromatic hydrocarbon emissions, both of which are considered carcinogenic," (Schumacher et al., 2001). Pure biodiesel is essentially free of sulfur compared to petroleum diesel. Biodiesel blends, consequently, contain less sulfur than petroleum diesel. Since biodiesel is renewable and can be domestically produced, it is capable of strengthening United States energy security by reducing dependence on imported oil (Morris, 1993).

A large amount of research has been carried out on the performance of engines fueled with biodiesel, including biodiesel produced from colza, soya, sunflower, and rapeseed oil. However, there is limited data regarding biodiesel produced from cottonseed oil. With the large amount of cotton produced in the United States, and the growing need for utilizing agricultural byproducts, it is important to investigate engine performance using biodiesel from cottonseed oil, as well as analyzing the exhaust emissions produced. Figure 1 illustrates the trend of cotton production in the United States since 1995.

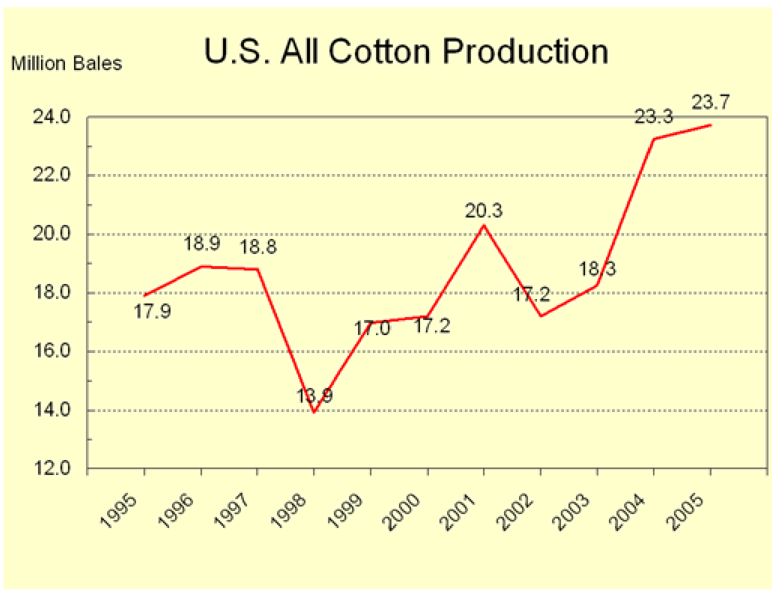

Figure 1. United States cotton production by year (USDA, 2006).

Cottonseed and cottonseed meal are commonly used for livestock feed. Cottonseed oil can be used as a food oil, as well as a source of biodiesel. According to the U.S. Census Bureau (USDOC, 2005), the United States produced about 880 million pounds, or about 117 million gallons, of cottonseed oil in 2004.

Biodiesel can serve several purposes: lubrication, which is seen with blends of two to five percent biodiesel (B2-B5); fuel supplement, which is seen with blends in the area of twenty percent biodiesel (B20); and as a stand-alone fuel, when pure biodiesel (B100) is used. As mentioned previously, blends such as B2 or B5 can be utilized as a lubricating fuel in place of high sulfur fuel. According to the NBB (2006b), "there is a marked improvement in lubricity when biodiesel is added to conventional diesel fuel". Most engine manufacturers warrant engines for use with these small percentage blends, and many manufacturers require that new vehicles leave the lot with these types of blends. Some manufacturers warrant the use of biodiesel blends up to B20 in diesel engines. Very few manufacturers warrant the use of B100 in diesel engines. It is important to note that federal law prohibits voiding an original equipment manufacturer, or OEM, warranty just because of the use of biodiesel in an engine; the biodiesel has to be the *cause* of the failure in order for the warranty to be voided (USDOE, 2004).

The objective of this research is to determine the correlation between diesel engine performance and the percent cottonseed oil biodiesel used in the fuel. The primary indicator for comparison of fuel blends is brake specific fuel consumption (BSFC).

Experimental Method

Performance curves will be developed for a three-cylinder 19 horsepower (hp) Yanmar diesel engine fueled by several blends of cottonseed oil biodiesel. The fuels to be analyzed include non-road, locomotive, and marine diesel fuel (NRLM), commonly known as red diesel, straight diesel fuel (DF) with 500 ppm sulfur, B5, B20, B40, B60, B80, and B100. Performance curves will be developed according to the Engine Power Test Code for diesel engines (SAE, 1983). As laid out in the Engine Power Test Code, the test measurements below are required in determining engine power:

- *Torque;*
- *Engine speed;*
- *Engine, water, oil, and ambient temperatures; and*
- *Inlet air pressure.*

The engine to be tested shall be representative of the manufacturer's production units, and the fuel used shall conform to the manufacturer specifications. To define the power curve, data should be recorded for five or more evenly spaced operating speeds between the lowest stable speed and the maximum speed recommended by the manufacturer. The following data will be recorded during engine testing (SAE, 1983):

- *Engine speed;*
- *Beam load;*
- *Ambient air temperature, pressure, humidity;*
- *Inlet air pressure, temperature;*
- *Exhaust system pressure;*
- *Fuel supply temperature;*
- *Oil and coolant temperature;*
- *Oil pressure;*
- *Intake manifold temperature, pressure;*
- *Exhaust manifold temperature, pressure;*
- *Air cleaner and piping restriction;*
- *Ignition/injection timing; and*
- *Fuel supply pressure.*

The engine will be loaded for tests with a water cooled eddy current absorption dynamometer rated at 30 hp, manufactured by Pohl Associates, Inc. Dynamometer load will be controlled using a Dynamatic® EC 2000 controller. Figure 2 shows dynamometer test system.

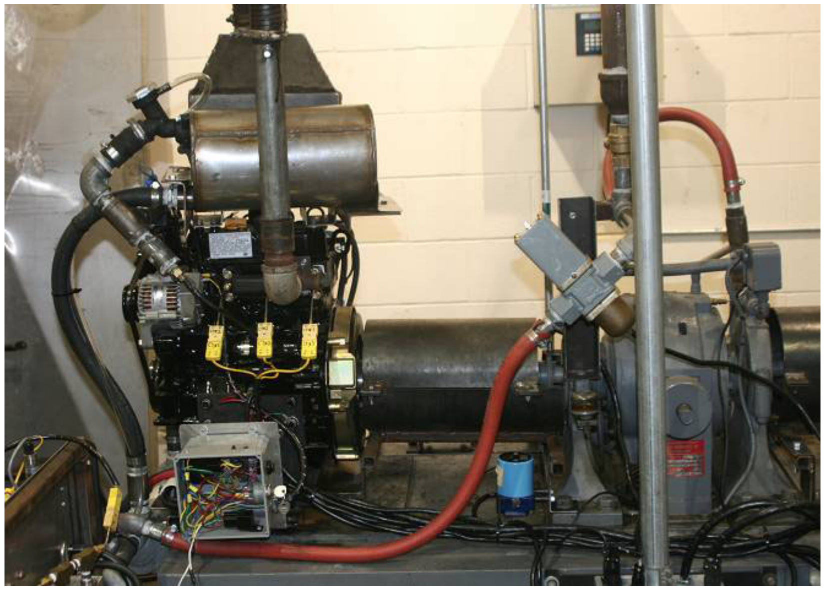

Figure 2. Dynamometer test system.

For each fuel blend, the engine will be started and allowed to warm up for several minutes at half throttle. The throttle will then be increased until the engine reaches full open throttle. Once full open throttle is obtained, a load will be applied to the engine. The load will be increased to the highest possible load at which the engine remains at maximum speed, which is about 3200 revolutions per minute (rpm). Once engine speed and torque measurements have been stable for two minutes, data will be collected for two minutes. The load on the engine will then be increased, while full open throttle is maintained, until the engine speed decreases to a desired level. Tests are to be completed for five evenly spaced engine speed intervals (1700, 2075, 2450, 2825, and 3200 rpm).

Engine speed and torque are used to determine horsepower of the engine at any given interval. Torque is found using equation 1:

$$P = \frac{T \times N}{9{,}549} \tag{1}$$

Where,

P = power, kW
N = engine speed, rpm
T = torque, N•m

Brake specific fuel consumption (BSFC), which is a good comparator of fuel blends, is a measure of the fuel efficiency of an engine. BSFC is the ratio of the rate of fuel consumption to the rate of power production using that fuel, and has units of grams per kilowatt-hour (g/kW-hr) when using the metric system. BSFC is, essentially, a function of the energy content of a fuel. Red diesel has an energy content of about 39,000 kilojoules per liter (kJ/L), while cottonseed oil biodiesel has an energy content of about 33,500 kJ/L. Equation 2 is used to find BSFC.

$$BSFC = \frac{f}{0.10472 \times N \times 0.001 \times T} \tag{2}$$

Where,

BSFC= brake specific fuel consumption, g/kW-h;
f = fuel consumption, g/h;
N = engine speed, rpm; and
T = torque, N•m.

The performance test outlined previously will be replicated three times for each fuel blend, using three randomized blocks, with each block containing one test for each mixture. Brake specific fuel consumption of different fuels will be compared using a T-test with a confidence interval of 0.95. These tests will determine whether or not there is significant difference in the BSFC of two fuels.

Results for this range of fuel blends will provide a thorough understanding of the affect of cottonseed oil biodiesel on engine performance. A correlation between percent biodiesel in a fuel and brake specific fuel consumption at a given engine speed and load is expected. It is also expected that there will be no significant difference in BSFC when compared to NRLM and DF with blends of B5 and B20.

Summary

Using biodiesel blends is a means by which sulfur concentrations in fuel, and, ultimately, SO_2 emissions from diesel engines, can be reduced. Also, the lubricity of biodiesel is utilized when small biodiesel blends are used. The use of a renewable natural resource in the form of biodiesel also helps lessen American dependence on foreign oil. Cottonseed is a viable source of oil that can be used to produce biodiesel. It is important to quantify the impacts on air pollutant emissions and engine performance that come with the use of cottonseed oil biodiesel blends in diesel engines. These performance and emissions tests are needed.

It is also critical that exhaust emissions be analyzed for biodiesel blends. Future research will include measuring and analyzing exhaust concentrations of nitrogen oxides (NO_x), sulfur dioxide (SO_2), total hydrocarbons (THC), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs). The relationship between cottonseed oil biodiesel blends and exhaust emissions will be determined.

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