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Diesel vehicle performance on unaltered waste soybean oil blended with petroleum fuels

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HIGHLIGHTS

- ▶ We examine engine performance on unaltered waste soybean oil-petroleum fuel blends.
- ▶ Fuels containing 15%, 30%, 40% and 50% waste soybean oil were created for analysis.
- ▶ Power and torque were analyzed on three vehicles on a chassis dynamometer.
- ▶ Performance for 15%, 30% and 40% WVO blends averaged 1.1% less than pure diesel.
- ▶ Performance for the 50% WVO blend was 5.4% lower than pure diesel.

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ABSTRACT

Interest in using unaltered vegetable oil as a fuel in diesel engines has experienced an increase due to uncertainty in the crude oil market supply and the detrimental effects petroleum fuels have on the environment. Unaltered vegetable oil blended with petroleum fuels is less expensive, uses less energy to produce and is more environmentally friendly compared to petroleum diesel or biodiesel. Here we investigate the engine performance of unaltered waste soybean oil blended with petroleum diesel and kerosene for three vehicles. Five biofuel blends ranging from 15% to 50% oil by volume were tested on a 2006 Jeep Liberty CRD, a 1999 Mercedes E300 and a 1984 Mercedes 300TD. A DynoJet 224x chassis dynamometer was used to test vehicle engine performance for horsepower and torque through a range of RPMs. Results for the Jeep showed a modest decrease in horsepower and torque compared to petroleum diesel ranging from 0.9% for the 15% oil blend to 5.0% lower for the 50% oil blend. However, a 30% oil blend showed statistically better performance ($P < 0.05$) compared to petroleum diesel. For the 1999 Mercedes, horsepower performance was 1.1% lower for the 15% oil blend to 6.4% lower for the 50% oil blend. Engine performance for a 30% blend was statistically the same ($P < 0.05$) compare to diesel. Finally, horsepower performance was 1.1% lower for the 15% oil blend to 4.7% lower for the 50% oil blend for the 1984 Mercedes. Overall, the performance on these oil blended fuels was excellent and, on average 1.1% lower than petroleum diesel for blends containing 40% or lower waste soybean oil content. The more significant decrease in power between the 40% and 50% oil blends indicates that oil content in these blended fuels should be no more than 40%.

1. Introduction

Since the year 2000, gasoline and oil prices have tripled while use and demand has also grown worldwide. Countries with emerging economies, such as China and India, are increasing consumption of gas and oil at record rates. In addition to a potential shortage of fuel to meet the growing demand, there is great concern that the use of fossil fuels for energy is a leading cause of a global warming trend which could lead to undesirable climate change. Economical, environmentally friendly, and sustainable energy solutions are needed to slow the growth and use of fossil fuels.

It is well known that vegetable oil can be used as an energy source in diesel engines. In fact, the first diesel engine developed by Rudolph Diesel was showcased at the 1900 World Fair where he demonstrated the use of peanut oil as a fuel for his engine [1]. It was not until Rudolph's death that his original engine design was converted to operate on petroleum diesel due to the increasing availability of petroleum products. The concept and practice of operating a diesel vehicle on unaltered vegetable oil has had resurgence in recent years, due to the sharp increase in petroleum costs

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and consumption as well as the detrimental effect on the environment. Furthermore, vegetable oil is considered to be nearly a net zero carbon emission fuel because the carbon produced by combustion, typically as carbon dioxide, is absorbed back from the atmosphere by plants [2]. The amount of process energy required to create vegetable oil is minimal, especially when compared to the requirements to produce petroleum diesel or even biodiesel [3]. However, current diesel automotive engine technology does not match well to widespread use of vegetable oil as fuel due to its relatively high viscosity at atmospheric temperatures [4].

One popular solution to the high viscosity is altering the vegetable oil through a chemical synthesis process where the lipid triglyceride (oil) molecule is broken apart at the ester functional group on each fatty acid chain connected to the triglyceride backbone. The end result of this base catalyzed transesterification reaction is the creation of four lower molecular weight molecules, glycerol and three methyl esters. The resulting methyl esters, termed Biodiesel, can then be used directly in a diesel engine or, as more typically done, used as a percent component in petroleum diesel fuel because it has a viscosity and gel point similar to petroleum diesel.

An alternative approach is to use chemically unaltered vegetable oil by retrofitting the engine fuel supply system with in-line heat exchangers and a heated fuel tank to lower the oil viscosity. This allows more appropriate flow through the fuel system, fuel injector spray patterns and nebulization of the fuel [5,6]. The complicating issue is that the engine needs to be started and operated on diesel fuel until the temperature of the vegetable oil in a separate fuel tank and supply system is at least 75 °C, which requires the addition of either manual fuel switching mechanisms or an automatic fuel switching system that selects the fuel based on temperature. At this temperature the oil has viscosity similar to that of diesel fuel. Before the engine is stopped, it again needs to be operated on the diesel fuel to purge the fuel system of oil. While this approach has experienced some success [7–14], retrofitting a vehicle with a separate fuel supply system and tank is impractical and cost prohibitive when considered on a large scale. Historically, long term engine wear and coking have also been concerns when operating on 100% unused (neat) or waste vegetable oil (WVO) [15–19]. Most of the issues and concerns reported in these early research efforts are likely due to poor atomization, and insufficient oxygen/air intake levels in the engine cylinder. The diesel engine designs used in these experiments operated at much lower fuel injection pressures than systems found on diesel engines today. As injection pressure increases, nebulization becomes more uniform and the fuel droplet size is smaller [20], which enables a more complete combustion process. Finally, it is not clear in these reports if the fuel was preheated to lower viscosity before injection into the engine.

A more practical approach to using unaltered vegetable oil effectively in diesel engines is to lower the viscosity by blending it with other petroleum fuels, such as diesel. There is a growing body of literature and research showing good success with this relatively simple approach. Rakopoulos et al. is one of the more prolific researchers in this area with reports dating back to 1992 indicating the possibility and efficacy of oil–diesel blends [21–23]. More recent reports by this group continue to show that oil–diesel blended fuels have comparable power performance and emissions to that of petroleum diesel fuel [24–26]. In all these reports the engines were mounted in a laboratory connected to a dynamometer and exhaust gas analysis system. Other investigators, using similar setups, have also reported comparable results for emissions and thermal efficiency of vegetable oil–diesel blends in stationary mounted engines in laboratory settings. While some of these studies use multi-cylinder engines [27–30], many are simple one cylinder engines [31–38]. In general, the thermal efficiency of oil–diesel blends has been found to be slightly lower, but effectively comparable to pure diesel [27,30,33]. In addition, exhaust gas and engine temperatures are lower with oil–diesel blends, which can be correlated to lower nitrogen oxides (NOx) emissions. Emission levels of unburnt hydrocarbons (HCs), and soot are somewhat mixed among research groups. Most reports do show a lower level of carbon monoxide (CO) when operating on oil–diesel blends. Ultimately, none of the exhaust emission levels are extreme compared to regulation levels. As such, oil–diesel blends can be regarded as a very reasonable alternative fuel that can reduce petroleum fuel use. Certainly, heating a diesel–oil blended fuel prior to injection into the engine to further reduce viscosity is possible and can improve engine performance compared to the same fuel that is unheated [31,32].

Since there appears to be a growing body of positive results for using oil–diesel blends on stationary engines in the laboratory setting, it brings to bear the question of how such fuels will perform in mass production diesel vehicles available to the consumer. The focus of the research efforts presented here was to create blended biofuels with viscosities low enough to allow direct use in mass produced vehicles with little or no modifications and evaluate the power and performance of each vehicle using chassis dynamometer measurements. In addition, on-road performance and fuel economy was assessed. Ultimately, our long range goal is to create practical, economical, and environmentally friendly biofuels by blending waste vegetable oil (WVO) with other petroleum fuels. While using neat vegetable oil makes it easier to control oil physical properties, the cost is much greater for us than obtaining WVO at no cost and processing it to remove particulates and water. Further, using WVO eliminates the debate and concern over using these resources for food versus fuel and provides a means to recycle a waste product.

2. Experimental methods

This work consisted of first creating appropriate fuel blends using semi-empirical modeling methods to guide the blend ratios and components and then evaluating performance through chassis dynamometer testing and on-road vehicle performance. Theoretical viscosity modeling of the fuel blends were conducted to determine what blend ratios would be possible in order to lower the viscosity to a specified value while maximizing the energy and oil content. In previous work conducted by the authors, viscosity modeling methods for fuel blends containing any combination of diesel, kerosene, waste vegetable oil and gasoline were developed [39]. Using these semi-empirical methods resulted in many possible blend ratios of diesel, kerosene, oil, ethanol and gasoline that achieve a desired viscosity. Energy content of the fuel needs to be maximized as well. Therefore, our viscosity modeling methods were used, along with energy content values for each component, so that engine performance could be maximized while achieving the identified viscosity limits. By multiplying heats of combustion values for each component with its percent loading in the blend and then summing to obtain the total blend heat of combustion, we were able to model and find specific blend compositions that should produce the highest energy content and presumably the best fuel efficiency and power. The cetane rating of a compression ignition fuel is a very important factor as well and should be monitored in blend formulations. However, it is not a physical property that can be accurately modeled through a summative state function method like heats of combustion. Further, our group does not have access to facilities and equipment to perform cetane measurements as outlined in the ASTM D976 method [40]. Vegetable oils tend to have a slightly lower cetane number compared to petroleum diesel, which can potentially lower engine performance