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Impact of biodiesel and renewable diesel on emissions of regulated pollutants and greenhouse gases on a 2000 heavy duty diesel truck

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HIGHLIGHTS

- Effect of biodiesels (BD) and renewable diesel (RD) on regulated emissions (RE) was investigated on a chassis dynamometer.
- BD showed higher degree of emission reductions for PM, THC, and CO than RD.
- BD showed significant increases in NO_x emissions for 50% or higher blends.
- BD and RD impacts on CO_2 and N_2O emissions were of lower magnitude relative to other RE.

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ABSTRACT

As part of a broad evaluation of the environmental impacts of biodiesel and renewable diesel as alternative motor fuels and fuel blends in California, the California Air Resources Board's (CARB) Heavy-duty Diesel Emission Testing Laboratory conducted chassis dynamometer exhaust emission measurements on in-use heavy-heavy-duty diesel trucks (HHDDT). The results presented here detail the impact of biodiesel and renewable diesel fuels and fuel blends as compared to CARB ULSD on particulate matter (PM), regulated gases, and two greenhouse gases emissions from a HHDDT with a 2000 C15 Caterpillar engine with no exhaust after treatment devices. This vehicle was tested over the Urban Dynamometer Driving Schedule (UDDS) and the cruise portion of the California HHDDT driving schedule. Three neat blend stocks (soy-based and animal-based fatty acid methyl ester (FAME) biodiesels, and a renewable diesel) and CARB-certified ultra-low sulfur diesel (CARB ULSD) along with their 20% and 50% blends (blended with CARB ULSD) were tested. The effects of blend level on emission characteristics were discussed on $g \cdot km^{-1}$ basis. The results showed that PM, total hydrocarbon (THC), and carbon monoxide (CO) emissions were dependent on driving cycles, showing higher emissions for the UDDS cycles with medium load than the highway cruise cycle with high load on per km basis. When comparing CARB ULSD to biodiesels and renewable diesel blends, it was observed that the PM, THC, and CO emissions decreased with increasing blend levels regardless of the driving cycles. Note that biodiesel blends showed higher degree of emission reductions for PM, THC, and CO than renewable diesel blends. Both biodiesels and renewable diesel blends effectively reduced PM emissions, mainly due to reduction in elemental carbon emissions (EC), however no readily apparent reductions in organic carbon (OC) emissions were observed. When compared to CARB ULSD, soy- and animal-based biodiesel blends showed statistically significant increases in nitrogen oxides (NO_x) emissions for 50% or higher biodiesel blends. The 20% blends of the biodiesels showed no statistically significant effect on NO_x emissions on any cycle. In contrast, renewable diesel slightly decreased NO_x emissions and the degree of reduction was statistically significant for 50% or higher blends over the UDDS cycle, but not at the 20% blends. The highway cruise cycles did not show a statistically strong NO_x emission trend with increasing blend level of renewable diesel. Biodiesel and

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renewable fuel impacts on two greenhouse gases, CO_2 and N_2O emissions were of lower magnitude when compared to other regulated pollutants emissions, showing a change in their emissions within approximately ±3% from the CARB ULSD.

1. Introduction

Biodiesel is a widely recognized renewable and alternative fuel for diesel engines which meets the U.S. Environmental Protection Agency (EPA) registration requirements for fuels. The use and production of biodiesel has been growing for the past decade and it is projected to continue with the trend as governmental programs and regulations promote the use of increasing levels of biofuel in the transportation sector to reduce greenhouse gas emissions (when a complete carbon life cycle is considered). For instance, the California Governor's Executive Orders S-1-07 (Low Carbon Fuel Standard, LCFS) and S-06-06 have spurred biofuel development in California by establishing targets for biofuel production and use while pursuing 10% reduction in the carbon intensity of California's transportation fuels by 2020 (Farrell and Sperling, 2007). In addition, the Federal Renewable Fuel Standard (RFS) under the Energy Independence and Security Act of 2007 mandated that a minimum of 500 million gallons of biomass-based diesel fuel must be used in the United States in 2009. On August 6, 2013, the EPA released its finalized volume and percentage standards for four renewable fuel categories – cellulosic, biomass-based diesel, advanced biofuels, and total renewables – under the 2013 RFS program. The EPA proposes the use of 16.55 billion gallons of renewable fuels in the transportation sector, corresponding to a percentage standard of 9.74% (ratio of renewable fuel volume to gasoline or diesel volume) (US EPA, 2013a).

A number of studies have suggested that biodiesel can lead to higher NO_x emissions (Karavalakis et al., 2009; Cheung et al., 2009; Durbin et al., 2011; Hajbabaei et al., 2012). The potential for increase in NO_x emissions has been recognized as a major concern to the application of biodiesel. This concern has resulted in a number of earlier studies to measure NO_x emissions from various biodiesel mixtures (Durbin et al., 2000; US EPA, 2002; McCormick et al., 2006; Sze et al., 2007; Durbin et al., 2011).

Renewable diesel is a synthetic diesel fuel with no oxygen and aromatic compounds, which is produced based on the hydrogenation of fatty acids. In order for some consistency, renewable diesel will be regarded as a diesel substitute from a renewable feedstock which are not esters. Chemically, it involves direct catalytic hydrogenation of plant oils and animal fats which mainly consist of triglycerides, into the corresponding alkanes. Side products of this hydrogenation include propane and gasoline components. The process has input flexibility to convert any vegetable oil or animal fat into an aliphatic product with characteristics similar to Fischer-Tropsch synthetic diesel. Though there are differences with each company, renewable diesel is usually subjected to thermal hydrotreating or pyrolysis-rapid thermal processing. Unlike the yellow transesterified biodiesel, the product is a clear and colorless hydrocarbon fuel, with a good Cetane number and better combustion properties than even petroleum-based diesel. Engine dynamometer emissions testing using 100% NExBTL renewable diesel reported reducing NO_x emissions by 5–18% and PM by 5–28% compared to CARB-certified ULSD (Hajbabaei et al., 2012). Most of the studies on vehicle emissions have been generally focused on biodiesel impact using an engine dynamometer (McGill et al., 2003; Fang et al., 2008; Hajbabaei et al., 2012). However, little investigation has been done examining whole vehicles on Chassis Dynamometer on the effect of blend levels of renewable diesel fuels on regulated emissions, global warming gases, and chemical composition of particulate matter in terms of a chassis dynamometer.

The California Air Resources Board's (CARB) Heavy-Duty Diesel Emission Testing Laboratory conducted exhaust emission measurements from in-use heavy-duty vehicles on a chassis dynamometer with the purpose of comparing the regulated and greenhouse gas emissions impact of biodiesel and renewable diesel and blends to CARB ULSD over a range of driving cycles. To achieve the goal of this study, a renewable diesel fuel and two biodiesels with different feedstocks (soy- and animal-based diesels) were used.

According to 2012 data compiled by R.L. Polk for the Diesel Technology Forum, more than 28% of all trucks registered in the United States (i.e., 2.5 million of the 8.6 million trucks) are equipped with diesel particulate filter (DPF) (Polk, 2013). It is expected that the number of DPF-equipped vehicles will continue to increase. Even though the truck tested in this study lacks of exhaust after-treatments and categorized into a fading technology vehicle, this is an important class of diesel vehicles from an emission stand point, as the majority of the emissions will be contributed by high emitters in the near future. In addition, it will provide a reference for comparison and evaluation on the impact of biodiesel and renewable diesel on regulated emissions between not only controlled and uncontrolled vehicle emissions, but also chassis dynamometer and engine dynamometer tests. This study was conducted as part of a broad evaluation of the environmental impacts of biodiesel and renewable diesel as motor fuels in California.

2. Experimental procedures

2.1. Testing facility

This study was conducted at the California Air Resources Board's Heavy Duty Emission Test Laboratory (HDETL) in Los Angeles which is equipped with a heavy-duty chassis dynamometer. The chassis dynamometer (Schenck-Pegasus unit) is driven by a direct current (DC) 447 kW (600 HP) motor that can absorb up to 492 kW (660 HP). It utilizes a single 182.9 cm (diameter) roller and has the capacity to simulate inertial weights from 2268 kg to 45,359 kg (5000 to 100,000 lbs). The chassis dynamometer cell is equipped with an 45.7 cm (diameter) full exhaust flow dilution tunnel (constant volume sampler, CVS). The total flow in the CVS during the testing was 70,792 LPM (2500 SCFM) maintained by a critical flow venturi. The dilution air is filtered through a HEPA filter and carbon cartridges to remove particles and gaseous impurities. The mixed flow (flow of vehicular exhaust and dilution air) is fed to a train of gaseous and PM instruments. The emission testing system is based on the Code of Federal Regulations Section 40, Part 86, and Subpart N.

2.2. Vehicles and cycles

The details of the test vehicle are described in Table 1. This vehicle was a Freightliner truck equipped with a 2000 C15