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Combustion Chemistry of Biodiesel for Use in Urban Transport Buses: Experiment and Modeling

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The study found that the use of biodiesel in public transit buses results in lower emissions of particulate matter (PM), combustion elements (mainly sulfur), elemental carbon, and carbon monoxide than petroleum-based fuels.

Biodiesel is of increasing interest as an alternative to conventional fuels because it offers the promise of fuel-source sustainability and reduced environmental impact.

However, biodiesel combustion chemistry and characterization of the exhaust require more in-depth study due to a number of issues observed in emissions and applicability of pure biodiesel. Some major issues are the lower heating value compared to regular diesel, less favorable cloud point, higher viscosity, which causes poor combustion, possibly high emission of NO_x, and variation of chemical properties between different feedstocks and blends.

Study Methods

The study tested combustion of biodiesel from various types of feedstock, such as soybean methyl ester (SME), tallow oil (TO), and waste cooking oil (WCO) in a variety of volume percent blends with ultra-low-sulfur diesel or ULSD (B00, B20, B50, and B100) using a laboratory bench-top combustion chamber. Different combinations of combustion temperature and pressure were applied to investigate their effects on emissions. In addition, physical properties (flash point, cloud point, and kinematic viscosity) of all biodiesel blends were measured.

Particulate matter (PM) samples were collected through field tests to investigate the source of elements in the emission gases released by buses. A similar procedure was followed to collect and analyze PM from the laboratory combustion experiments to determine precisely which elements were from biodiesel fuels. The field study used ten different transit buses running on B20, which contains 20 vol% of SME with 80 vol% ULSD, in both hot and cold idle modes. Emission gases were analyzed using gas chromatography to measure concentrations of emission components in the exhaust.

Findings

A total of eleven inorganic and metal elements were detected in the laboratory experiments, while fifteen elements were observed in field experiments. Calcium, sodium, and iron were the major elements found in the PM emissions in both the field experiments (77 – 85 wt%), and the lab experiments (up to 90 wt%).

Based on gravimetric analysis, PM emissions significantly decreased by less than 17% on average when using B20 compared to ULSD, and newer transit buses showed a greater PM reduction (more than 98% on average) than old buses. For both hot and cold idle tests, a substantially high reduction in total PM was observed with B20 compared to ULSD.

Elemental carbon (EC) and organic carbon (OC) analyses of the collected PM from field tests were also conducted. OC/EC analyses showed that more OC was emitted during cold idling (>80%) than in hot idling (>65%). The OC/EC ratio was found to be greater for new buses with catalytic converters (9.57 – 13.37) than for old buses without converters (1.85 – 4.55). Modeling showed that four sources — oil (including fuel and engine oil), lubricant, engine parts, and ambient conditions — contributed heavily to the generation of PM in the exhaust.

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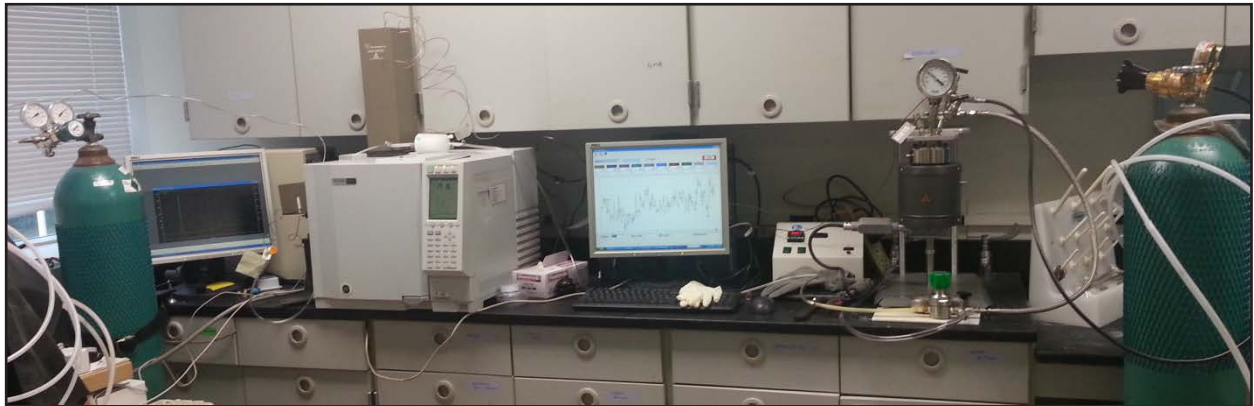
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Laboratory test results indicated that when the volume percentage of biodiesel increased in the blends, the combustion temperature and pressure linearly increased. The high oxygen content of biodiesel is thought to be the reason for this increase at the tested combustion temperature and pressure, which also is thought to contribute to the reduction of PM. The results also confirmed that better combustion occurred in hot idle mode than in cold idle mode.

Biodiesel physical properties tests revealed that SME biodiesel has better fuel properties than TO and WCO, and it releases low emissions compared to TO, WCO, and ULSD. It was observed that when the kinematic viscosities of the biodiesel samples were high, the PM emissions were low. A low flash point was observed to result in less fuel wastage. In addition to the experimental results, simple reaction kinetic models were proposed to better understand the formation mechanism of PM and to predict the concentrations of PM and other combustion components.



Laboratory setup for biodiesel study, including a gas tank, gas chromatograph, and combustion chamber.

Policy Recommendations

Biodiesel is being industrialized as one of the potential sources of sustainable energy for transportation in the future. The results of different analyses on biodiesel emissions suggest that PM emissions are dependent on the engine modes (temperature) and type of fuel (feedstocks) and blends. The results indicate that the use of biodiesel could effectively reduce EC, which is considered more hazardous than OC, and increase the ratio of OC/EC emission.

It can be concluded that biodiesel has many advantages over regular diesel even in a very low blend percentage. The benefits include lower emissions of PM, combustion elements (mainly sulfur), EC, and carbon monoxide (CO) than petroleum-based fuels. Thus, it is recommended that governments consider using blends of biodiesel in urban and commercial vehicles to enhance the quality of air and to promote healthy living.

About the Authors

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For more details about the study, download the full report at transweb.sjsu.edu/project/1146.html