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Combustion and Emissions Investigations of a New Biodiesel and Biodiesel Blend

Author: Martin Muiños, Georgia Southern University

GEORGIA SOUTHERN UNIVERSITY

Introduction

- The EPA estimates that over 11 million older diesel engines are still in use and are emitting high levels of harmful emissions such as particulate matter and nitrogen oxides (NO_X). The older diesel engines, that predate the current EPA emissions standards, are capable of producing large amounts of harmful emissions.
- 36 billion gallons of advanced biofuels are to be included in the national fuel pool by 2022, as mandated by the Energy Independence Security Act of 2008. Biodiesel is an attractive alternative to the gradually-diminishing petroleum based fuels. The use of advanced biofuels have been shown to decrease harmful emissions without the use of an exhaust aftertreatment system.
- Biodiesel is also a renewable fuel that can be produced from a variety of feedstocks, such as grass, corn, used vegetable oils, and animal fats.
- This study focuses on a new biodiesel and a green biodiesel blend. The biodiesel (C100) is derived from Brassica carinata (carinata). The biodiesel blend (C90+BU10) consists of 90% carinata biodiesel and 10% n-butanol. The blend is completely renewable. N-butanol is an alcohol fuel produced from fermenting waste biomass.
- Compared with other oilseed crops, carinata is agronomically superior, frost tolerant, and drought tolerant. Brassica carinata is very capable of being a winter crop in the Southeast United States.

Fuel Formulation and Analysis

- Carinata biodiesel was produced through transesterification of crude carinata bio-oil using methanol and a sodium hydroxide catalyst. The resulting fatty acid methyl ester (FAME) was then washed, dried, and filtered. N-butanol is an alcohol fuel similar to ethanol. N-butanol is used in this study due to its higher energy density and favorable thermal stability properties.
- Various thermo-physical properties of the experimental fuels were investigated in order to determine the suitability for engine use and are presented in Table 1. The viscosity of the biodiesel(C100), although much higher than conventional diesel (ULSD#2), was still within the acceptable range as defined by ASTM D6751. The influence of n-butanol is evident in the biodiesel blend (C90+BU10), as the lower heating value, dynamic viscosity, and thermal stability decreased.

Table 1: Thermo-Physical Properties of Experimental Fuels

	ULSD#2	C100	C90+Bu10	n-butanol
Cetane Number	47	52	49.3	24.8
Fuel Density (g/mL)	0.85	0.875	0.868	0.807
Lower Heating Value (MJ/kg)	42.7	41.4	40.6	33.1
Dynamic Viscosity at 40 °C (cP)	2.34	5.05	3.98	1.81
Molecular Weight (g/mol)	200	324	-	74.1
TA10 (°C)	111.9	231.9	190.0	52.3
TA50 (°C)	180.4	285.2	266.7	78.2
TA90 (°C)	234.5	325.1	304.8	92.2

- The thermal stability of fuels is an important characteristic because of its implications in injector spray formulation. Fuels with very high thermal stability tend to produce larger droplet diameters during injection. Finer droplets in an injection spray is favorable in order to achieve a more complete vaporization and premixing before combustion.

Engine Instrumentation and Combustion Analysis

The experimental investigations were carried out at a constant speed of 1500 rpm and a constant load of 4 bar indicated mean effective pressure (IMEP). Engine experiments were conducted with ULSD#2 as a baseline. The experimental engine instrumentation is presented in Figure 2.

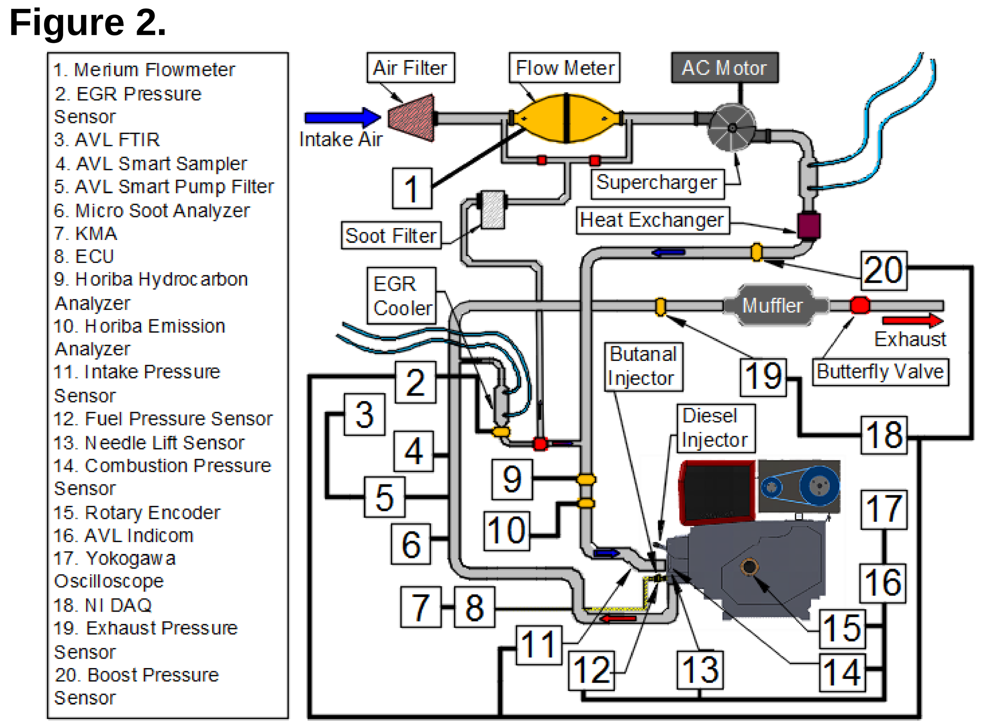

FIGURE 1: Experimental Engine Setup

TABLE 2: Experimental Engine Specifications

Maximum Power	17 kW /2200 RPM
Maximum Torque	77.5 N·m/1400 RPM
Bore × Stroke	112 mm × 115 mm
Displacement (single cylinder)	1132 cm³
Injection Nozzle	4 orifices × 0.200 mm
Injection Pressure	200 bar
Injection timing	16° BTDC
Compression Ratio	16:1

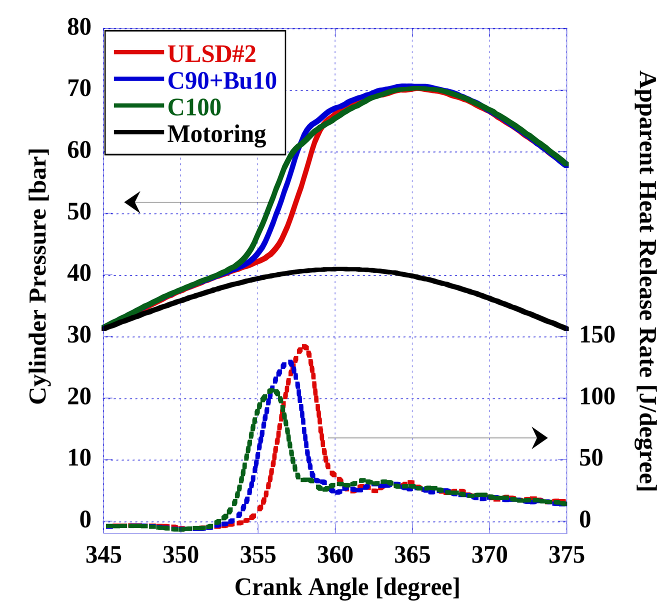

FIGURE 2: Cylinder Pressure and Needle Lift

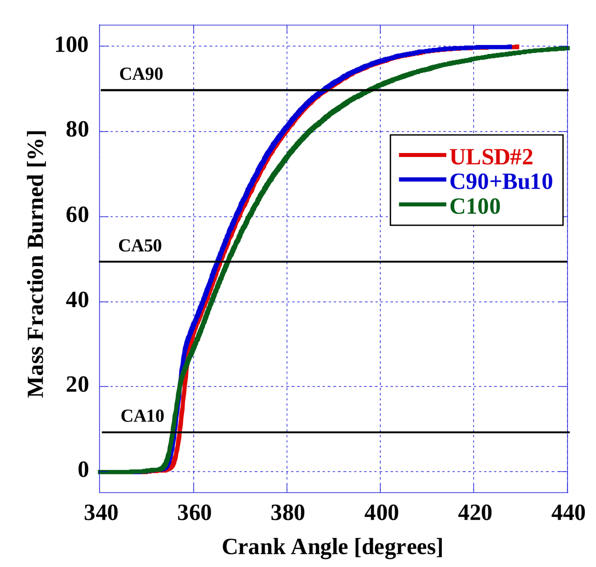

FIGURE 3: Mass Fraction Burned

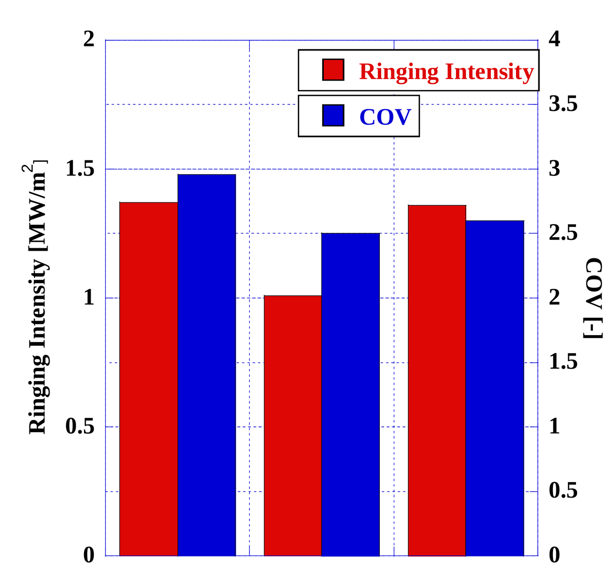

FIGURE 4: Ringing Intensity and COV of IMEP

- The results of the combustion investigation are presented in the Figures 2-4. The maximum combustion pressure for all fuels were similar at 73 bar.
- The biodiesel and biodiesel blend exhibited lower peak heat release rates, when compared to ULSD#2. Biodiesel, in general, have higher cetane numbers than ULSD#2, and is evident by the diminished ignition delay of both C100 and C90+Bu10. As the ignition delay is reduced, the premixed combustion heat release peak becomes diminished.
- The combustion phasing was shifted when using biofuels. C100 exhibited a longer combustion duration and an extended CA50. With the addition of n-butanol in the blend, the combustion event was accelerated which resulted in a combustion phasing very similar to ULSD#2.
- Ringing intensity is a pressure wave based correlation for the noise generated from engine operation. ULSD#2 and C90+BU10 exhibited nearly identical ringing intensities of 1.36 MW/m², as seen in Figure 4. C100 had the lowest ringing intensity of 1 MW/m².
- The coefficient of variation (COV) of the IMEP is used as a metric for combustion stability and is averaged over 300 engine cycles. The COV remained under 3.0 for all fuels, which indicates stable combustion for the fuels tested.

Table 3: Combustion Phasing and Ignition Delay

	ULSD	C100	C90+Bu10
CA50 [CAD]	366	367.3	365.3
Ignition Delay [CAD]	9.0	8.1	8.5
Ignition Delay [ms]	1.0	0.9	0.94
Combustion Duration [CAD]	31.5	42.3	32.1

Emissions and Efficiency Analysis

Soot and nitrogen oxides (NOX) emissions formulation during combustion occur simultaneous. Traditionally, reducing one of the pollutants leads to an increase of the other. However, a simultaneous reduction was observed for the biofuel and biofuel blend, The C90+BU10 blend exhibited a 59% decrease in soot without any exhaust aftertreatment systems, as shown in Figure 5. C100 showed a 14% decrease in soot emissions when compared to ULSD#2. There was a 5% decrease in NO_X for C100 and 8% decrease for C90+Bu10. The simultaneous reductions in soot and NO_X have the potential to reduce respiratory issues in areas that use carinata biodiesel.

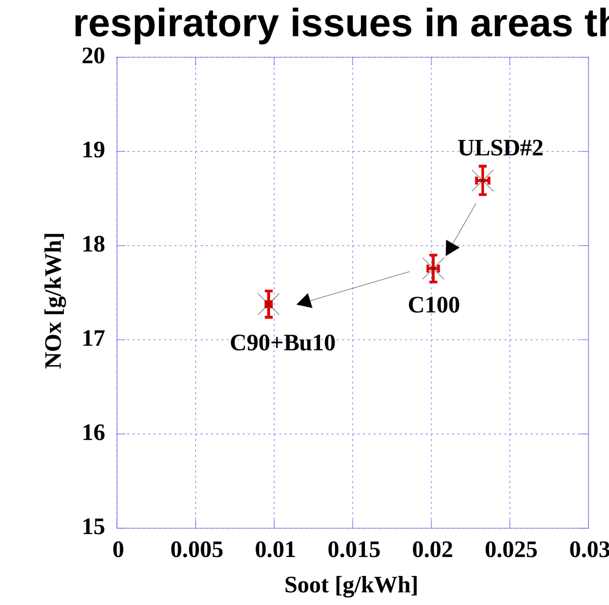

FIGURE 5: Soot and NO_X Tradeoff

- The carbon monoxide emissions saw a 12% increase in for the C90+BU10 blend and an 8% decrease for C100, when compared to the ULSD#2 baseline. Unburned hydrocarbon (UHC) remained relatively constant for all tested fuels.
- The Brake Specific Fuel Consumption (BSFC) increased by 10% for C90+BU10 and C100 when compared to ULSD#2.. The mechanical efficiency for ULSD#2 was 74%, increased to 76% for C90+BU10, and decreased to 73% for C100.

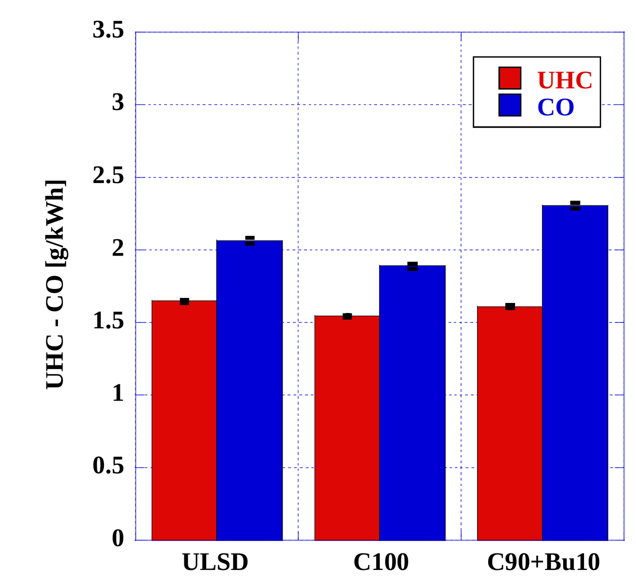

FIGURE 6: CO and UHC Emissions

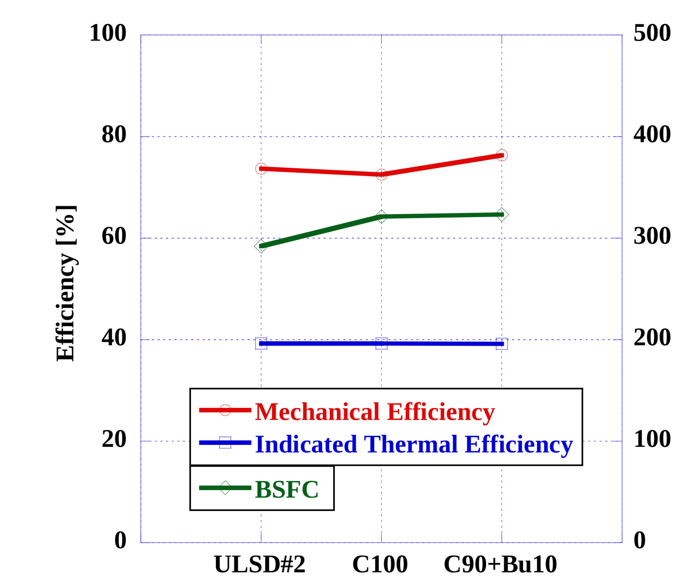

FIGURE 7: Efficiencies and Fuel Consumption

Conclusion

- In this study, the combustion and emissions characteristics of carinata biodiesel and a carinata biodiesel-n-butanol blend were investigated at 1500 rpm and 4 bar IMEP. The biodiesel produced from the Brassica carinata plant was investigated due to the potential for immediate use as a winter crop in the Southeast United States.
- The engine investigation proved that C100 (100% carinata biodiesel) and C90+BU10 (90% carinata biodiesel and 10% n-butanol by mass) can be utilized in a compression ignition engine without modification and with minimal effects to the combustion phenomena.
- NO_X decreased by 5% for C100 and by 8% for C90+BU10 when compared to ULSD#2. The soot emissions also showed a favorable trend with a 14% decrease for C100 and a 58% decrease for C90+BU10 when compared to ULSD#2.
- The results of this study suggest that carinata biodiesel and carinata biodiesel blends are capable alternatives to ULSD#2 with advantages in soot and NO_X emissions formations.