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Effects of diesel and biodiesel blends on engine performance and efficiency

Christopher L. Hunt^{}, Donald Johnson[†], and Don Edgar[§]*

ABSTRACT

Tests were conducted during the summer of 2009 on a John Deere 3203 diesel tractor to determine differences in specific fuel consumption (sfc), power take-off (PTO) torque (Nm), and PTO power (kW), between ultralow sulfur No. 2 Diesel (D2), 20% biodiesel (B20), 50% biodiesel (B50), and 100% biodiesel (B100). Four 1-hr tests were conducted with D2, while three 1-hr tests were conducted with B20, B50, and B100. The results indicated that there was no significant ($p < 0.05$) difference between D2 and B20 for power or torque. Fueling with B50 resulted in significantly lower power and torque than fueling with D2 or B20, but significantly higher power and torque than fueling with B100. There were significant differences between each fuel in sfc; as the biodiesel blend increased, sfc also increased. Based on these data, B20 appears to be the optimal biodiesel blend for this and similar compact utility tractors since fueling with B20 resulted in no significant loss in power or torque (compared to D2) and only a slight increase in fuel consumption.

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MEET THE STUDENT-AUTHOR



Christopher Hunt

I am currently a senior majoring in agricultural education, communication and technology. I graduated from Paragould High School in 2007 and enrolled at the University of Arkansas that fall. I was awarded the Ring Scholar in 2008 and several college scholarships. I am a member of Collegiate FFA/4-H, Agricultural Mechanization Club, Alpha Zeta, and AEED REPS.

During the summer of 2009 I began working with Dr. Don Johnson and Dr. Don Edgar on a research project concerning biofuels and their effects on engine performance. Through this research, I have gained many valuable experiences. The research that was conducted has allowed me to compete in the Gamma Sigma Delta poster contest. I plan to continue my education in graduate school after receiving my B.S. degree.

INTRODUCTION

With the increasing cost of petroleum-based fuels and U.S. dependency on them, the agricultural equipment industry is attempting to produce more compact utility equipment capable of operating on biodiesel and biodiesel blends (Cousins, 2006). Research is needed to determine the optimal blends of petroleum diesel and biodiesel for use in these vehicles.

Biodiesel is a renewable fuel manufactured from vegetable oils, cooking greases and oils, or animal fats (DOE, 2006). More technically, biodiesel is defined as “a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D6751” (NBB, 2007). ASTM D6751 establishes specific laboratory tests, methods, and minimum standards for biodiesel quality. Most current U.S. biodiesel is produced from the methyl ester of soybean oil, since this oil crop is available in sufficient quantities to supply the national market (Canakci and Van Gerpen, 2003).

Researchers (Proc et al., 2006; Canakci and Van Gerpen, 2003; and Schumacher et al., 2001) have found little difference in power performance, specific fuel consumption, or thermal efficiency between engines fueled with No. 2 petroleum diesel (D2) or with blends of up to 20% biodiesel and 80% D2 (B20). Decreased power and increased specific fuel consumption have been found in engines fueled

with neat biodiesel (B100), since it contains approximately 12.5% less energy than D2 (DOE, 2006).

This purpose of this study was to determine if there were significant ($p < 0.05$) differences in power take-off (PTO) power, PTO torque, or specific fuel consumption (sfc) for a compact diesel tractor fueled with D2, B20, B50, and B100 under variable load conditions. The findings from this study may be used in selecting the optimal biodiesel blend for compact diesel tractors similar to the one used in this study.

MATERIALS AND METHODS

Test Fuels. One 18.93-liter container of each test fuel was provided by FutureFuel Chemical Co. (Batesville, Ark). FutureFuel is certified as a BQ-9000 producer by the National Biodiesel Board. BQ-9000 is a voluntary certification program of the National Biodiesel Accreditation Commission that ensures that accredited producers meet rigorous quality standards for production, sampling, storage, and testing of biodiesel. Samples of each fuel were collected and transported to the FutureFuel laboratory for analysis (Table1).

A John Deere 3203 compact utility tractor (Deere and Co., Moline, Ill.) with a Yanmar three cylinder, four-stroke compression-ignition diesel engine was used to test all fuels. Engine load was manually applied using an AW NEB-400 (Colfax, Ill.) PTO dynamometer. An auxiliary

fuel tank and Ohaus D-35 digital platform scale (Pine Brook, N.J.) were used to measure mass fuel consumption. The fuel system was drained and the fuel filter was replaced prior to testing each fuel. For each test, the engine was warmed up under moderate dynamometer load. After warm-up, the load was removed and the governor control was set to high idle speed (approximately 2970 engine RPM). Dynamometer load was then applied decreasing engine speed to 2900 RPM and in subsequent 100 RPM decrements. This process continued until the tractor operated at peak torque output (1600 engine RPM). The load was held at each RPM for three minutes. Fuel weight was recorded at the beginning and end of each three-minute period. PTO torque (Nm), PTO power (kW), and RPM were logged automatically at one second intervals (1 Hz). Specific fuel consumption was calculated as kg/kWh. Ambient environmental conditions were monitored to ensure tests were conducted in compliance with the OECD Tractor Test Codes (OECD, 2006).

Before switching fuels, the auxiliary fuel tank was drained completely and filled with the next test fuel. The engine was then operated for 10 minutes with all return line fuel collected in a separate tank. After the fuel system was purged, the fuel filter was changed and the bypass line was reconnected to the auxiliary fuel tank for the next test fuel. Data were analyzed using analysis of variance procedures.

RESULTS AND DISCUSSION

There were significant ($p < 0.0001$) differences between fuels in PTO power, PTO torque, and specific fuel consumption when the effect of engine speed was held constant (Table 2). There were no significant differences in either power or torque between D2 and B20. However, fueling with B50 resulted in significantly less power and torque than either D2 or B20, but significantly more power and torque than B100. There were significant differences in specific fuel consumption between each of the four fuels. Specific fuel consumption increased as the percentage of biodiesel increased. This increase in specific fuel consumption was consistent with the decreased energy content of the fuels as compared to D2. Figures 1-3 present PTO power, torque and specific fuel consumption for each fuel across engine speeds. These figures indicate that differences between the fuels previously described were consistent regardless of tractor load.

The results of tests performed support previous research that little difference in power, torque, and specific fuel consumption results when an engine is fueled with D2 or B20 (DOE, 2006). Conversely, there are significant differences when engines are fueled with blends of biodiesel containing greater than 20% biodiesel compared to those with less than 20% biodiesel.

In this study the researcher did not examine or take into account the potential differences in engine wear, fuel system degradation, or start temperatures or other issues associated with biofuels. Consumers should take these issues into account and consult the manufacturer's warranty and recommendations in selecting biodiesel blends for use in diesel engines.

CONCLUSION

Switching to B20 biodiesel for use in compression ignition engines could result in no significant difference in performance (power or torque) with only a slight (2.8%) increase in specific fuel consumption. However, use of B50 and B100 resulted in a significant decrease in torque and power and a significant increase in specific fuel consumption compared to D2. Thus, blends higher than B20 are not recommended for this or similar compact diesel tractors unless the decreased performance and increased fuel consumption are offset by reduced fuel costs.

ACKNOWLEDGEMENTS

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Table 1. Chemical and Physical Properties of No. 2 petroleum diesel (D2), 20% biodiesel blend (B20), 50% biodiesel blend (B50), and 100% biodiesel blend (B100).

Fuel Property	D2	B20	B50	B100
Heat of Combustion (MJ/kg)	45.66	44.16	42.09	40.30
Specific Gravity (@15C)	0.85	0.85	0.86	0.88
Sulfur (ppm)	8.70	6.40	6.30	NA ¹
Free Glycerin (%)	NA ¹	Not Detectable	Not Detectable	0.01
Total Glycerin (%)	NA ¹	0	0	0.01
Iodine Number	1.60	13.40	27.10	48.90
Viscosity (CS@40C)	2.49	2.62	3.20	4.55

¹NA stands for not applicable because the fuel type does not contain these properties.

Table 2. Mean PTO power, torque, and specific fuel consumption for tractor fueled with No. 2 petroleum diesel (D2), 20% biodiesel blend (B20), 50% biodiesel blend (B50), and 100% biodiesel blend (B100).

Fuel Type	Torque (Nm)	Power (kW)	Specific fuel consumption (kg/kWh)
D2	324.71 A ¹	14.64 A	0.286 A
B20	322.4 A	14.52 A	0.294 B
B50	316.75 B	14.27 B	0.303 C
B100	306.56 C	13.80 C	0.326 D

¹Means in the same column with the same letter are not significantly different at the 0.05 alpha level.

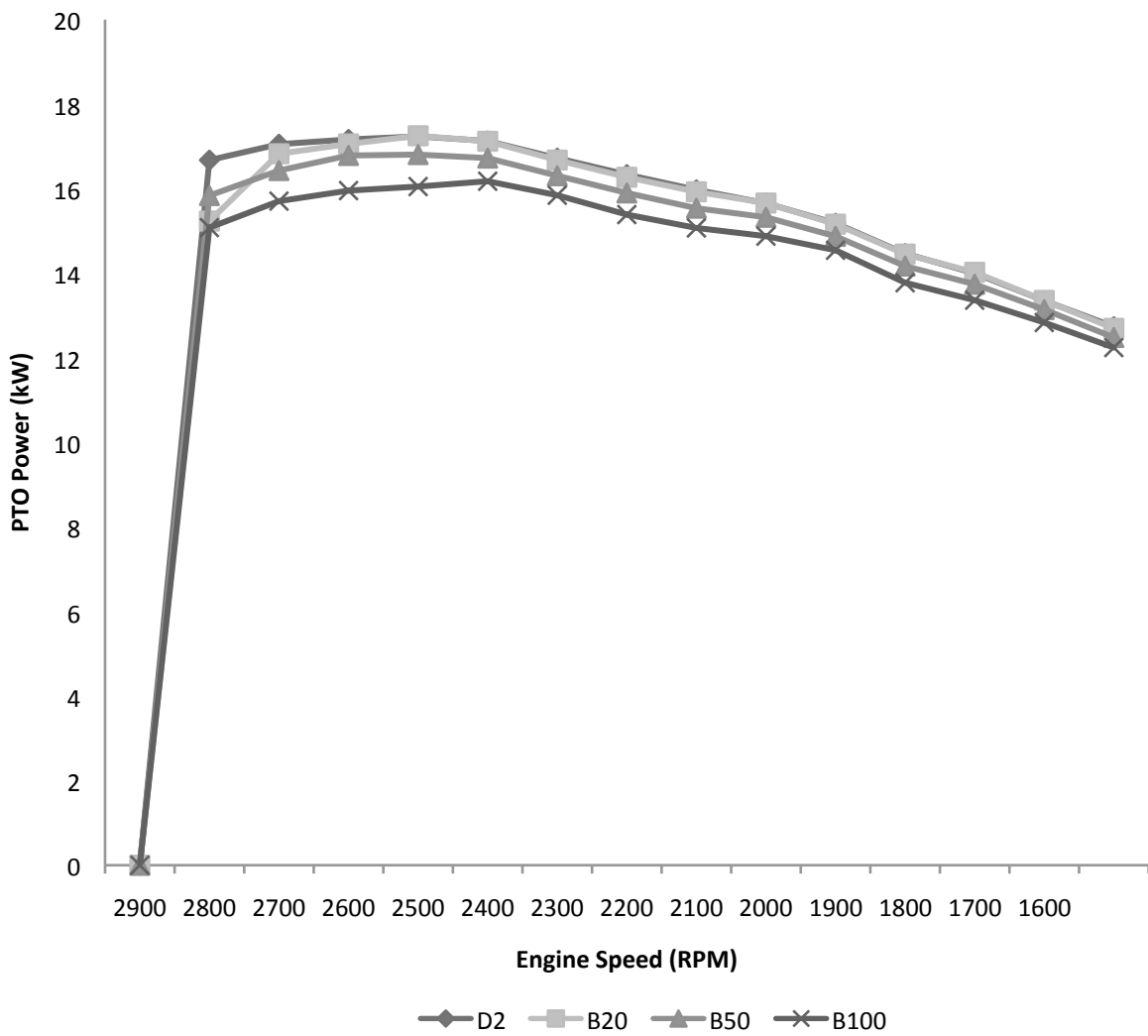


Fig. 1. Power take-off (PTO) power by engine speed for tractor fueled with No. 2 petroleum diesel (D2), 20% biodiesel blend (B20), 50% biodiesel blend (B50), and 100% biodiesel (B100).

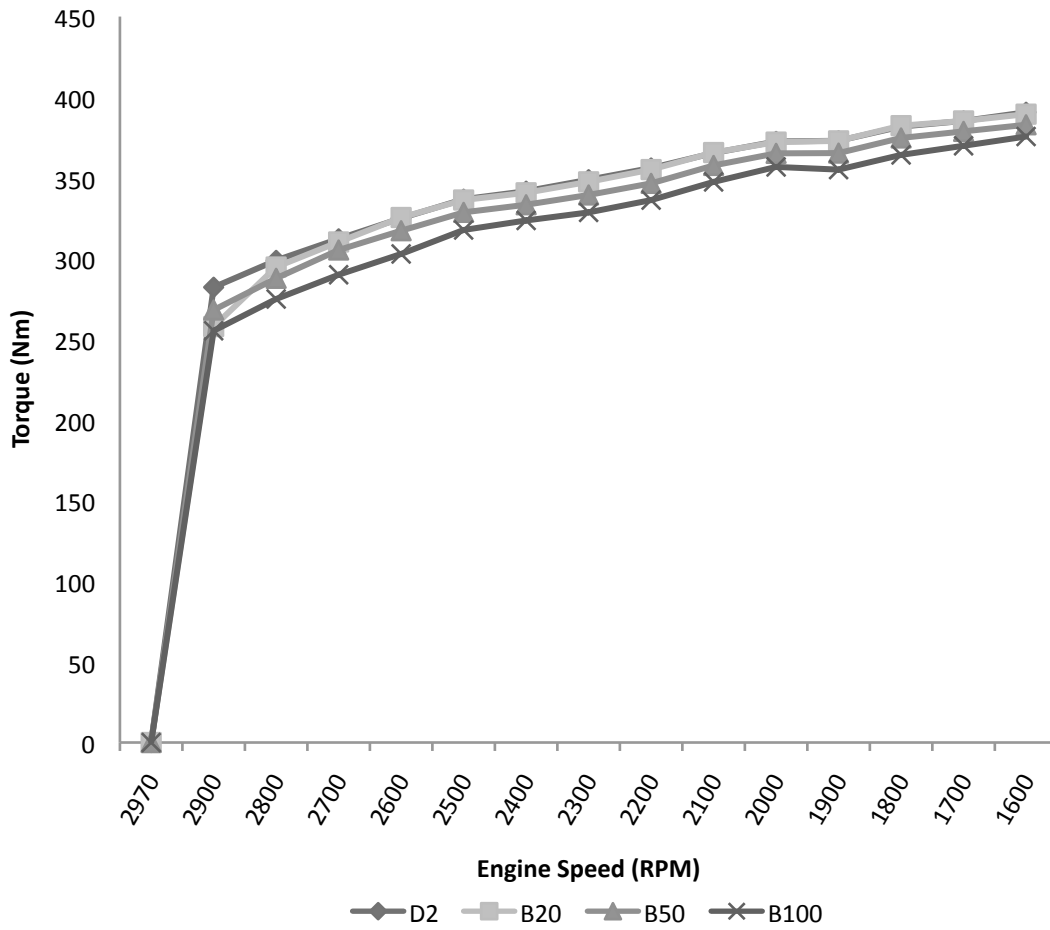


Fig. 2. Power take-off (PTO) power by engine speed for tractor fueled with No. 2 petroleum diesel (D2), 20% biodiesel blend (B20), 50% biodiesel blend (B50), and 100% biodiesel (B100).

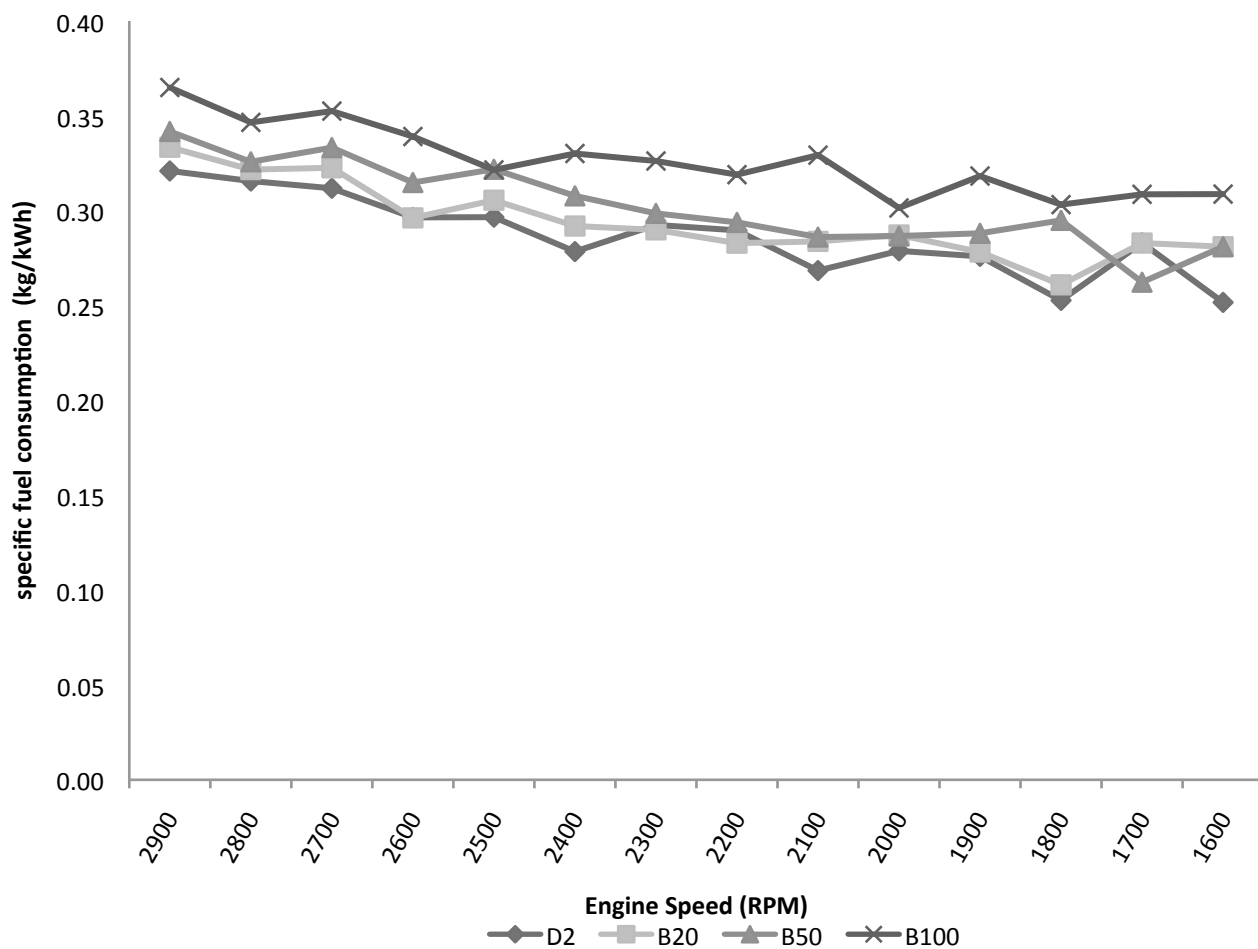


Fig. 3. Specific fuel consumption for tractor fueled with No. 2 petroleum diesel (D2), 20% biodiesel blend (B20), 50% biodiesel blend (B50), and 100% biodiesel (B100). Specific fuel consumption is calculated as kg/kWh.