

AN INSTRUMENTED DIESEL ENGINE SYSTEM FOR RESEARCH AND EDUCATION OF ALTERNATIVE FUELS

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ABSTRACT. *This article reports the development and demonstration of an instrumented diesel engine test system for the assessment of power performance, fuel efficiency, and exhaust emissions of alternative diesel fuels. The system was composed of a 4-cylinder diesel engine (60 kW), water-brake dynamometer (294.2 kW), fuel stand, 5-gas emission analyzer, two computers, a data acquisition system, and various sensors to measure the engine performance parameters. The fuel stand allowed for changing the direction of the fuel supply between the diesel fuel tank and the alternative fuel tank, and measured the instantaneous fuel consumption. The data on engine performance, fuel consumption, and exhaust emissions were monitored and recorded as a text file for analyses and comparisons. The elements of the engine system and fuel test procedure were demonstrated to 40 students during the testing of biodiesel-diesel fuel blends. The students' knowledge of the diesel engine test system components and fuel test procedure were evaluated through a survey instrument administered before and after the laboratory demonstrations. The survey results indicated that the engine test stand was effective in demonstrating to college students the significant parameters for the evaluation of alternative fuels.*

Keywords. *Instrumentation, Diesel, Exhaust emissions, Engine performance, Biodiesel.*

Limited oil reserves, environmental concerns, dependence on imported oil, economic instability due to fluctuating oil prices and the desire for energy independence are among the major reasons for increased interest in the research and development of alternative transportation fuels. Biodiesel, produced from oil-seeds, animal fats and used vegetable oils, is an attractive renewable fuel for reducing harmful emissions from diesel engines (Schumacher et al., 2005; Agarwal, 2007). Although biodiesel is marketed commercially in several countries, the acceptance and widespread use of biodiesel or other alternative transportation fuels require training and education of consumers. Consumers' beliefs about environmentally-friendly products affect their decisions regarding the type of vehicle they purchase and often they favor vehicles which produce low exhaust emissions (Van de Velde et al., 2009). Research on determining the factors affecting the acceptance of biofuel by consumers may inform market players as to whether or not to use certain propositions in their marketing and communication strategy to the general public (Popp et al., 2009).

The U.S. has attempted to increase the use of renewable fuels by setting a target volume of 36 billion gallons blended into transportation fuels by 2022 (EPA, 2012). The recent policies of biofuels are expected to encourage further expansion of biofuel use (Zawadzki et al., 2007; Sorda et al., 2010). In addition, the experience of the Transportation Department with biodiesel blends showed that biodiesel is gaining acceptance as a viable part of the fuel supply by the state agencies (Humburg et al., 2006).

In-depth research on alternative transportation fuels for diesel engines requires facilities to determine the engine performance and exhaust emissions of the investigated fuel alternatives. Stationary or mobile instrumented test stands with diesel engines in various sizes are used for research in several disciplines, including agricultural engineering. One of the educational priorities of the alternative transportation fuels research is to integrate the laboratory test results with field experiences that are designed to prepare the next generation of energy professionals to function in a multi-disciplinary environment (Duane, 2008). The availability of facilities is often variable and limits the ability to produce accurate results from alternative fuel tests. In addition to the commercial production of alternative fuels, some farmers and individuals are producing biodiesel from soybean oil, waste vegetable oil or animal fats in relatively small scales. The variability in feedstock sources and processes used for biodiesel production create biofuels that may not satisfy the quality standards. Individual fuel producers often have concerns about the quality of their fuel and some producers in Missouri contacted the Agricultural Extension staff and faculty members at University of Missouri for assistance in testing their fuels for engine performance and exhaust emissions. In addition to research and public service, the Agricultural Systems Management curriculum at the University of Missouri has

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three courses at freshmen, sophomore, and senior levels covering internal combustion engines in varying details. Improved facilities were needed at the University for researchers participating in multi-disciplinary research, education, and extension to study different types of transportation fuels.

OBJECTIVES

The objectives of this project were to set up an on-site diesel engine test system suitable for research and education of university students on testing diesel engines using a dynamometer. The specific objectives were to:

- Integrate a 4-cylinder diesel engine with a dynamometer; equip the setup with sensors, data acquisition system and computers.
- Test the system components by measuring the power, fuel efficiency and emissions of soybean oil biodiesel-diesel fuel blends.
- Evaluate the effectiveness of the system in teaching the materials and procedures of testing diesel engines using a dynamometer to freshmen students in an introductory Agricultural Systems Management course.

MATERIALS AND METHODS

ENGINE-DYNAMOMETER SET UP

A 2007 Cummins QSB 3.3, 4-cylinder, 60 kW (80 hp), four stroke; turbocharged diesel engine equipped with a mechanically controlled fuel injection pump was used for the test system. Three fuel tanks (19 L capacity), one each for the base fuel (certified # 2 diesel), experimental fuel and flushed fuel between tests were used in the system. The direction of the fuel supply and return lines between the fuel tanks and the engine fuel system were controlled with manual valves. A fuel stand was built to hold the fuel tanks. A cooling tower was used to control the engine temperature. The temperature of the cooling tower was controlled with a thermostatic valve. Eight thermocouples were mounted on the engine to measure the temperatures of the inlet air, fuel, turbocharger, engine cylinder, cooling water, and engine oil. A control box was built to hold the engine ignition key, throttle control valve, and the data acquisition terminal box. The engine was mounted on a

metal frame anchored to the floor. A 294.2 kW water-brake dynamometer (AW Dynamometer, Inc., Pontiac Ill.) was coupled with the engine to supply the engine load. The dynamometer was equipped with a load cell for engine torque measurement and a magnetic pick-up sensor for the measurement of the shaft speed. The dynamometer was directly connected to the engine flywheel using a high-speed driveline (AW Dynamometer, Inc., Pontiac, Ill.). The frequency readings from the magnetic pick up sensor were monitored using a digital indicator (Shimpo, Itasca, Ill.). The indicator displayed the engine speed (rpm) and converted the frequency to voltage for data recording. Approximately 40 m² area was surrounded with fences to control the access to the engine test area. The major components of the instrumented diesel engine test stand are shown in figure 1.

The data acquisition system had a NI-PXI platform and a NI-USB 6009 DAQ card (National Instruments, Austin, Tex.). Engine speed, torque and fuel consumption were measured via the USB DAQ card. The engine temperatures were measured at eight locations using K-type thermocouples connected to the NI-PXI terminal box. The NI-PXI platform was connected to a laptop using an express card (NI Express card-8360, National Instruments, Austin, Tex.). The signals from the torque and fuel consumption sensors were conditioned using amplifiers (OMEGA, DMD-465). The conditioned signals were captured with the USB-DAQ card. A program developed in Labview controlled the data acquisition system. The system captured the digital signals from the sensors, calculated, displayed, and recorded the engine performance parameters and emission gasses on the computer.

A portable exhaust emission analyzer (TESTO 350 XL, Flanders, N.J.) monitored the emissions of NO, NO₂, CO, CO₂, O₂, and exhaust temperature. The emission probe was mounted on the exhaust pipe and the analyzer was connected to a computer via serial connection. The emission analyzer allowed the recording of measurements at varying intervals in MS-Excel format. The analyzer was set to warm up for 20 minutes at ambient conditions before emission was measured. An opacity meter (Wagner-6500, Wager, Inc., Rural Hall, N.C.) mounted on the exhaust pipe measured the smoke opacity. The opacity meter had a light transmitter and receiver components. The transmitter

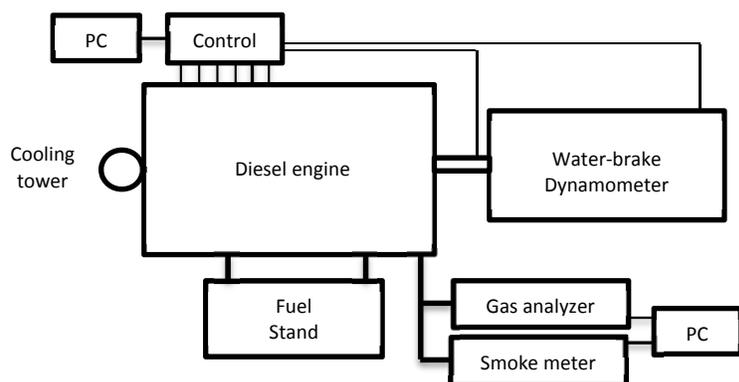


Figure 1. Major components of the diesel engine test stand and fuel stand, engine and dynamometer.

emitted a light and the receiver measured the amount of light detected. The difference between the two values is indicated as the opacity of the exhaust fumes. The opacity meter was enclosed to be operated indoors and mounted on the exhaust line. The temperatures of the transmitter and receiver were controlled by running water at a constant temperature through the sensor heads. Compressed air was used to keep smoke away from the transmitter and receiver lenses. Before each test, the opacity meter was calibrated with a calibration glass with a known opacity value. The opacity meter was connected to an indicator and to the data acquisition system for data recording.

TESTING THE SYSTEM COMPONENTS BY EVALUATING THE BIODIESEL-DIESEL FUEL BLENDS

Soybean oil biodiesel and certified #2 diesel blends were used to test the operability of the engine system components. Certified #2 diesel fuel was purchased from Brownfield Oil Company (Moberly, Mo.) and soybean oil biodiesel was obtained from Global Fuels LLC (Dexter, Mo.). Biodiesel was blended with diesel fuel volumetrically to obtain 5% (B5) and 10% (B10) biodiesel-diesel blends. The specifications for the diesel and biodiesel used for the tests are shown in table 1. Before the engine testing, the load cell on the dynamometer and the opacity meter were calibrated and the emission analyzer was turned on. The engine was fueled with certified #2 diesel fuel and the functionality of all the system components and sensors were checked.

DEMONSTRATION OF THE SYSTEM TO UNIVERSITY STUDENTS

The completed engine system was demonstrated to the students in the ASM 1020-Introduction to Agricultural Systems Management course. ASM 1020 is one of the required courses in the agricultural systems management program. The course provides a basic introduction to power and energy, grain handling, agricultural machinery, electricity, and soil and water. The students in ASM 1020 are mostly freshmen majoring in the departments of Agricultural Systems Management and Agricultural Education at University of Missouri. A laboratory session was devoted for teaching the materials and procedures used for testing a diesel engine using a dynamometer. A questionnaire was administered to the students before and after each session. The survey was comprised of 15 competency statements. The descriptors attached to each question on a Likert-type scale regarding the knowledge level were: 1: none, 2: below average, 3: average, 4: above average and 5: excellent. Table 2 shows the survey

Property	Certified #2 Diesel	B100	B5	B10
Density at 25°C (g/cm ³)	0.80	0.84	0.82	0.83
Viscosity at 40°C (mm ² /s)	3	4.1	3.3	3.4
Flash point (°C)	50	130	76	84
Cloud point (°C)	-12	4	-6	-4
Water content (%)	-	0.0072	-	-
Sulfur content (%)	0.0015	0.0003	0.0015	0.0018
Cetane number	57	48	-	-
Energy value (MJ/L)	40.3	33.4	-	-

Table 2. Survey of instrumented engine test stand.

Competency Statement	Knowledge Level ^[a]				
Characteristics of the braking system of a dynamometer	1	2	3	4	5
Mechanism of applying hydraulic load to a diesel engine	1	2	3	4	5
The cooling system of the dynamometer	1	2	3	4	5
Ballast used to keep the dynamometer stable during loading	1	2	3	4	5
How engine speed is recorded	1	2	3	4	5
Why engine speed is important	1	2	3	4	5
High speed driveline to connect the engine to the dynamometer	1	2	3	4	5
The test engine cooling system	1	2	3	4	5
How the fuel system was used to fuel the engine	1	2	3	4	5
Acquisition system for the temperature measurements	1	2	3	4	5
Acquisition system used to record engine torque	1	2	3	4	5
The system used to measure fuel consumption	1	2	3	4	5
Diesel engine exhaust emissions	1	2	3	4	5
The data collection system as a whole	1	2	3	4	5
Safety measures that are on the test stand	1	2	3	4	5

^[a] Knowledge level: 1- None, 2- Below Average, 3- Average, 4-Above Average, 5-Excellent.

elements which were administered to the students in a paper version in a laboratory setting before and after the demonstration.

RESULTS AND DISCUSSIONS

The diesel engine and the dynamometer were coupled and all the system components were assembled. Preliminary tests were conducted to check the operation of the system and sensors. During these tests, we observed that the readings from the sensors used to measure brake-specific fuel consumption were not accurate. Volumetric or gravimetric methods can be used to measure the fuel consumption during engine testing. Initially, two volumetric turbine flow rate sensors (FT-110 Series – Turbo Flow, Gems Sensors, Plainville, Conn.) were used to measure the fuel consumption. One of the flow sensors was connected to the fuel inlet line and the second sensor was connected to the fuel return line. The sensors were supplied with 12 VDC. The output signals from the sensors were square waves whose frequency varied linearly with the flow rate. The difference between the inlet and return line fuel flow rates were used to measure the fuel consumption in real time. The sensors were connected to the data acquisition system for online monitoring and recording. As the engine temperature increased during the preliminary tests, the fuel temperature in the fuel tank also increased. This increase was due to the increased temperature of the excess fuel returned from the injectors. To keep the temperature of the inlet fuel constant, a custom-made heat exchanger was installed on the fuel inlet line. A custom-made, tubular heat exchanger with 32 mm OD steel pipe and 80 cm length were used to control the temperature of the fuel. The fuel was supplied through four inner pipes (6 mm OD) and the refrigerated water was circulated around the inner pipes. The temperature of the circulating water could be adjusted between 0°C and 50°C (IsoTemp Refrigerated Circulator, Fisher Scientific, Waltham, Mass.). This type of arrangement provided fuel flow to the injectors at a consistent temperature. Despite this arrangement, the

turbine type flow rate sensors did not produce consistent fuel consumption measurements. We believed that this was due to the change in volume of fuel in the return line due to temperature increase as the fuel was passing through the injector heads. The inlet fuel temperature was controlled precisely but the temperature of the returned fuel was not. Because of the difficulties encountered in measuring the fuel flow rate, we changed the measurement method. We modified the fuel stand and mounted a load cell (SSM-AJ-50, MFG, Scottsdale, Ariz.) to measure the weight of the fuel tank continuously. The gravimetric measurement of fuel consumption produced more consistent and accurate readings than the volumetric measurements. In addition, the calibration of the load cell was much easier and the measurement of fuel consumption was not affected by variations in fuel temperature.

The dynamometer was coupled with the engine using a high speed drive line. The dynamometer's hydraulic control valves to adjust the engine load were replaced with new valves to prevent the oil leaks observed during preliminary testing. The new valves provided precise load control during the engine tests. Hoses and valves were connected to the dynamometer to provide continuous water flow around the dynamometer drum. Water inlet and drain line connections were also made to provide the cooling water to the engine cooling system. The water flow rates to the dynamometer and to the cooling tower were adjusted manually.

EVALUATION OF BIODIESEL-DIESEL FUEL BLENDS

The engine was operated with diesel fuel and then switched to biodiesel blend (B5 or B10). Two trials for each fuel type were conducted and the averages of the recorded data were used to evaluate the engine performance, fuel consumption, and exhaust emissions of biodiesel-diesel fuel blends and the results were compared with certified #2 diesel fuel (table 3). The standard deviations of the engine performance and emission characteristics explain the variations between the averages of the biodiesel and diesel trials.

The effects of biodiesel blends on engine brake power and torque outputs are shown in figure 2. The highest engine brake power was measured when the engine was fueled with diesel fuel. The peak power output was observed at 2000 rpm. On average, diesel fuel produced 3.6% and 5.9% more power than B5 and B10 ($p < 0.05$), respectively. Since biodiesel has a heating value that is less than diesel fuel on weight basis, the biodiesel blends caused

a reduction in engine brake power output (Agarwal, 2007; Lapuerta et al., 2008a). In addition, the higher viscosity of biodiesel compared to diesel fuel can explain the slight decrease in engine power (Xue et al., 2011). The higher thermal efficiency of biodiesel provides complete burning of the fuel in the combustion chamber and reduces harmful emissions (Ghobadian et al., 2009). The maximum torque of 255.5 Nm at 1800 rpm was measured when diesel fuel was used. The torque values for biodiesel blends were also measured at the same engine speed. The torque values for B5 and B10 were 2% and 3% less than the torque values measured for diesel fuel and these differences were statistically significant ($p < 0.05$). The reduction in power and torque outputs due to the use of biodiesel would be important for several industries in which diesel engines are used.

The effects of biodiesel fuel blends on brake specific fuel consumption (BSFC) are shown in figure 3. Increasing the biodiesel blend ratio increased the specific fuel consumption and the differences in BSFC between B5 and B10 were significant ($p < 0.05$). Both B5 and B10 produced higher brake specific fuel consumption than diesel fuel but these differences between the values for B5 and diesel, and B10 and diesel were not statistically significant ($p > 0.05$). The peak BSFC values for B5 and B10 were 14% and 24% more than diesel fuel. This result was due to the lower heating value of the biodiesel than diesel fuel in mass basis. The lower heating value of biodiesel was compensated with higher fuel consumption (Anand et al., 2011).

The NO_x emissions from the biodiesel blends were higher than diesel fuel and these differences were statistically significant ($p < 0.05$). B5 and B10 blends on an average produced 1.8% and 4.3% higher NO_x emissions than diesel fuel (fig. 4a). Fueling the engine with B10 produced the highest NO_x emissions under full load conditions. Reducing the engine load reduced the NO_x emissions for the fuel blends. Theoretically, a higher cetane number and lower aromatic hydrocarbon chains of biodiesel compared to diesel fuel should reduce NO_x emissions (Dong et al., 2008). However, the high oxygen content of biodiesel may cause higher NO_x emissions (de Guzman et al., 2010). Other researchers indicated that the high molecular weight of biodiesel compared to diesel fuel might be the reason for high NO_x emissions (Hess et al., 2007). Ban-Weiss et al. (2007) stated that none of these factors should be responsible for the NO_x characteristics of biodiesel alone, rather all these reasons are contributing factors affecting biodiesel emissions during combustion.

Biodiesel blends of B5 and B10 reduced the CO emissions on an average of 10.6% and 17.4% compared to diesel fuel and these differences were statistically significant ($p < 0.05$) (fig. 4b). Increasing the engine loads increased the CO emissions for all fuels. Biodiesel emissions of CO are affected by other parameters such as cetane number and ignition delay in the combustion chamber (Shi et al., 2006). There is not a unanimous conclusion about the effect of biodiesel blends on reducing CO emissions. Some researchers reported that biodiesel blends had no effect on CO emissions compared to diesel fuel (Lapuerta et al., 2008b). However, some researchers

Table 3. Measured and calculated engine parameters for the base fuel and biodiesel fuel blends.

Parameters	D100	B5	B10	SD ^[a]
Power (kW)	42.97	41.48	39.41	2.44
Torque (Nm)	213.88	203.35	191.08	11.45
BSFC ^[b] (kg/kWh)	0.239	0.252	0.268	0.25
NO_x (ppm)	873.57	889.42	912.71	19.68
CO (ppm)	2453	2191.71	2025.57	215.4
CO_2 (ppm)	9.2	8.35	8.01	0.61
Exhaust temperature (°C)	368.85	366.91	354.02	8.06
Engine temperature (°C)	397	378.57	368.57	14.42

^[a] SD: Standard deviation.

^[b] BSFC: Brake specific fuel consumption.

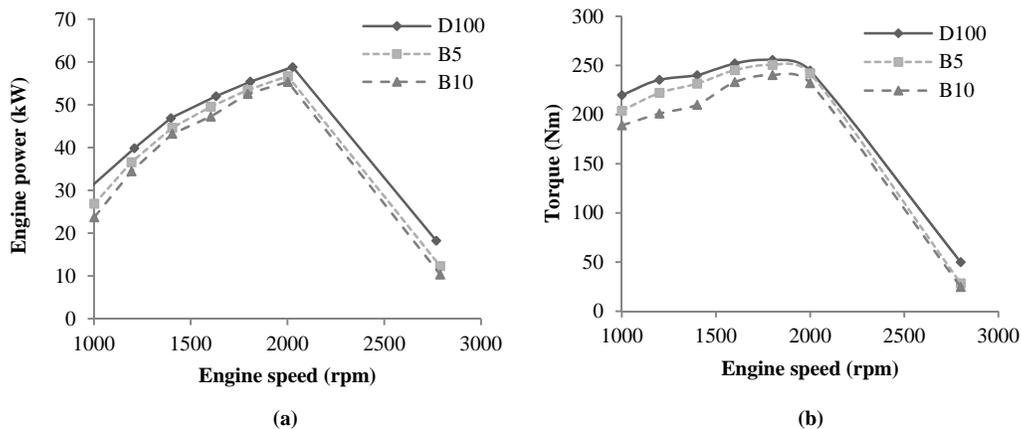


Figure 2. Change of engine power (a) and torque (b) with engine speed under varying loads.

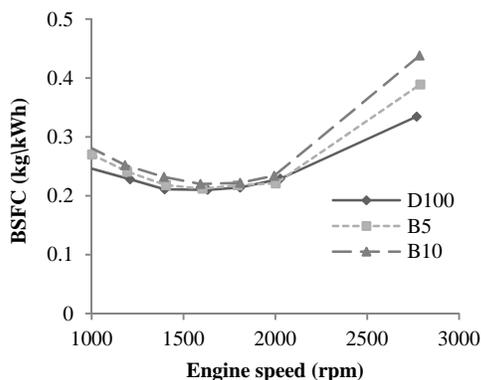


Figure 3. Brake specific fuel consumption (BSFC) change with varying loads.

indicated that biodiesel blends increased CO emissions significantly when compared to diesel fuel (Fontaras et al., 2009; Sahoo et al., 2009).

Diesel fuel produced higher CO₂ emissions than biodiesel blends (fig. 5). Increasing the engine load increased the CO₂ emissions for all of the fuels tested. The highest CO₂ emissions for biodiesel blends were observed when the engine was operated at 1200 rpm and the CO₂ was slightly reduced when the engine was operated at full

load. The differences between the CO₂ emissions from B5 and B10, and diesel were statistically significant ($p < 0.05$). The biodiesel blends at B5 and B10 reduced CO₂ by an average of about 9.3% and 13%, respectively. The general belief is that alternative fuels should reduce the emissions of greenhouse gases (Coronado et al., 2009). By contrast, some researchers reported that biodiesel produces higher CO₂ emissions than diesel fuel and they attributed this cause to the more efficient combustion of biodiesel (Ramadhas et al., 2005; Canakci, 2007). The results of this study showed that biodiesel produced lower CO₂ emissions than diesel fuel. The demonstration of biodiesel use in diesel engines may increase its acceptability as an alternative fuel. The increased acceptability of biodiesel would encourage consumers to utilize locally-produced fuel and, in turn, encourage the producers to provide more biofuel products.

The lower power and torque outputs of biodiesel blends compared to diesel fuel observed in this study agree with the literature. This is an expected result because the energy content of biodiesel is lower than diesel fuel. The CO and CO₂ emissions from biodiesel measured in this study agree with some of the literature results as well. According to a survey on biodiesel engine performance and emissions conducted by Xue et al. (2011), 80% of the literature

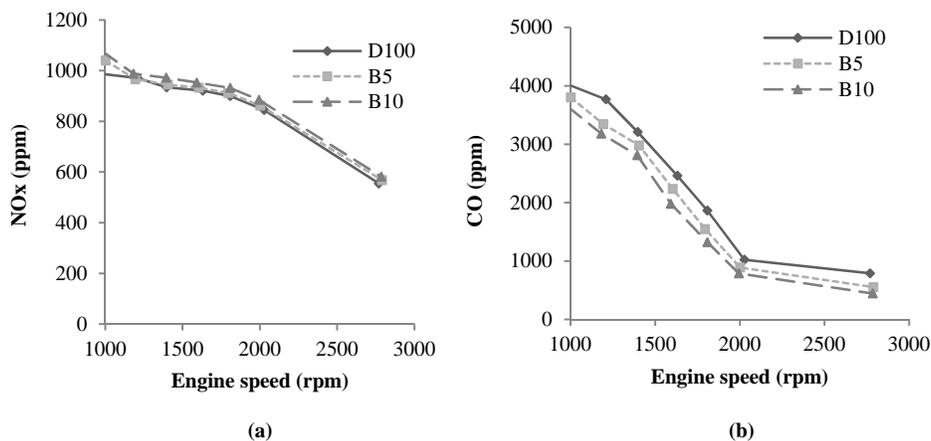


Figure 4. NO_x (a) and CO (b) emissions with engine speed under varying loads.

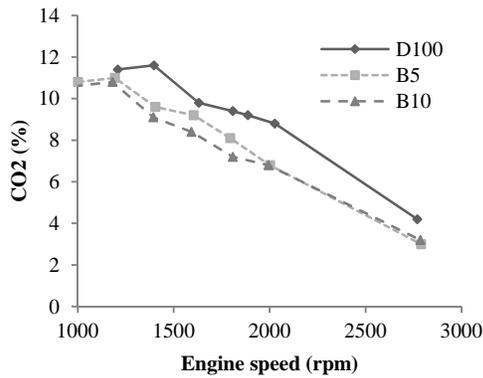


Figure 5. Change of CO₂ emissions with the engine speed under varying loads.

reported that biodiesel produced lower CO emissions and 53.8% of the literature reported that biodiesel produced lower CO₂ emissions. Higher NO_x emissions from biodiesel compared to diesel fuel observed in this study was also in agreement with the majority of the literature. There is no consensus on the effects of biodiesel on NO_x emissions. Some literature indicates biodiesel increases the NO_x emissions, others indicate the use of biodiesel decreases NO_x. Lapuerta et al. (2008a) reported that B100 would produce approximately 10% more NO_x than the same volume of petroleum diesel. Sun et al. (2010), in a review article on NO_x emissions from biodiesel-fueled diesel engines, indicated that there is not a consistent reason for the increase in biodiesel NO_x emissions. The size, operating conditions, combustion chamber, air and fuel system designs are among the reasons for the increase in biodiesel NO_x emissions (Sun et al., 2010; Hoekman and Robbins, 2012).

DEMONSTRATION OF THE SYSTEM IN TEACHING THE MATERIALS AND PROCEDURES OF TESTING DIESEL ENGINES

The instrumented diesel engine test stand was used to demonstrate the engine performance and exhaust emissions characteristics of alternative diesel fuels and to illustrate the methods used to evaluate the fuels for diesel engines using a dynamometer. The engine test system was set up before each laboratory session. Students were instructed about the moving parts and hot surfaces on the engine test stand and were provided with safety glasses and earplugs. The laboratory instructions and handouts were given to the students. Manuals for the dynamometer, exhaust emission analyzer and opacity meter were made available for the students. The principle of the water-brake dynamometer, sensors and their locations on the dynamometer were explained to the students. The calibration procedures for the load cells, speed sensor and opacity meter were explained and demonstrated to the students. Before the engine started, students were allowed to get familiar with the system components, sensors and the display monitor. At each laboratory session, two fuel tests were conducted.

The students in each laboratory session (10 students) were assigned to complete different tasks to get them

engaged in the activity. Two students were assigned to record the data from the emission analyzer and the engine performance data on separate computers. One student controlled the dynamometer valves manually to vary the load on engine during testing and another student checked the fuel levels in the fuel tanks and controlled the direction of the fuel flow. The course instructor and a teaching assistant were present during the tests.

STUDENT KNOWLEDGE BEFORE THE DEMONSTRATION

The results of the survey of the students' initial knowledge of the engine test stand are shown in table 4. The results showed that 73% of the students had no knowledge and 12% of the students had below average knowledge of the engine components and test procedure before the demonstrations. This result indicates that 85% of the respondents had very little or no knowledge of the evaluation of alternative fuels with engine tests. On the other hand, the initial survey indicated that 3% of the respondents had excellent knowledge of engine components and test procedures. The standard deviation among the levels of initial knowledge produced a high standard deviation (SD=49.49). It is believed that demonstrating the elements of the engine test stand and fuel testing would increase the student awareness of engine test controls and capabilities. The academic community and researchers should continue to provide information to positively affect the attitudes of the students, producers, and users on biofuels.

STUDENT KNOWLEDGE AFTER THE DEMONSTRATION

The overall knowledge of the respondents before and after the demonstration is shown in table 5. The survey results indicated that there is a lack of variation on engine test procedures and fuel tests based on the standard deviation between the means. Before the demonstration, the students' knowledge of the overall engine test procedure was none (level 1) and below average (level 2). After the components of the engine test system were identified and the fuel tests presented, the overall scores rose between levels 4 (above average) and 5 (excellent) on a 1-5 scale. The students' feedback on the data acquisition system changed significantly ($P < 0.05$) from 1.5 to 4.3 with a S.D. of 1.90. The students' knowledge of fuel consumption measurement increased from 1.52 to 4.1. Similarly, when the students were asked "how the engine fuel system worked" after the demonstration, the students' knowledge of fuel system operation reached an average of 4.4. When utilizing a data acquisition system to record engine torque, the student's knowledge of data acquisition increased from

Table 4. The knowledge of engine test stand before the engine demonstration.

Knowledge Classification	Total Responses	Knowledge Percentage
None	29	73
Below average	4	12
Average	2	7
Above average	2	5
Excellent	3	3
Total	40	100

Standard deviation = 49.49

Table 5. Survey results of instrumented engine test stand before and after the demonstrations.

Competency Statement	Average ^[a]		Std. Dev.
	Before	After	
Characteristics of the braking system of a dynamometer	1.37	4.30	2.06
Mechanism of applying hydraulic load to a diesel engine	1.55	4.52	2.10
The cooling system of the dynamometer	1.32	4.52	2.26
Ballast used to keep the dynamometer stable during loading	1.52	4.37	2.01
How engine speed is recorded	1.97	4.45	1.75
Why engine speed is important	2.00	4.25	1.59
High speed driveline to connect the engine to the dynamometer	1.90	4.35	1.73
The test engine cooling system	2.05	4.55	1.76
How the fuel system was used to fuel the engine	1.62	4.40	1.96
Acquisition system for the temperature measurements	1.50	4.20	1.90
Acquisition system used to record engine torque	1.55	4.27	1.92
The system used to measure fuel consumption	1.52	4.10	1.82
Diesel engine exhaust emissions	1.35	4.05	1.90
The data collection system as a whole	1.37	4.12	1.94
Safety measures that are on the test stand	1.42	4.25	1.99

^[a] Knowledge level: 1- None, 2- Below Average, 3- Average, 4-Above Average, 5-Excellent

1.55 to 4.27. Knowledge about the exhaust emissions also improved from 1.35 to 4.05 with a S.D. of 1.90. Knowledge of data collection from the whole system rose from 1.37 to 4.12. The most reasonable observation from this finding is that the students had a lack of knowledge of the components of the engine test system and fuel test procedure before the demonstrations.

A paired t-test was also performed to determine the overall effectiveness of the laboratory activity with the engine test system and demonstration. The mean difference in knowledge level before and after the demonstration of the engine test system (mean difference of 2.713 and standard deviation of 1.395) was significantly greater than zero. The t-value was 42.31 and the two-tail p-value was 2.5×10^{-15} which provided evidence that the laboratory activity with the engine test system demonstration was effective in teaching the materials and procedures on testing alternative fuels using a diesel engine test system. A 95% confidence interval about mean knowledge level difference was 2.58 and 2.84.

CONCLUSIONS

A 4-cylinder diesel engine was coupled with a water-brake dynamometer and instrumented with an exhaust emission analyzer, engine performance monitoring sensors, and a data acquisition system for testing alternative diesel fuels. The system components were tested by evaluating the power, fuel consumption, and exhaust emissions of B5, B10, and diesel fuels. The torque and power outputs for B5 and B10 were significantly lower than the diesel fuel. However, the differences between the brake specific fuel consumptions for B5 and diesel fuel, and B10 and diesel fuel were not statistically significant ($p > 0.05$). Increasing the biodiesel blend ratio from 5% to 10% increased the brake specific fuel consumption significantly ($p < 0.05$). B5

and B10 produced significantly higher NO_x emissions but lower CO and CO_2 emissions than diesel fuel.

The effectiveness of the developed system in teaching the materials and procedures of testing diesel engines using a dynamometer was demonstrated to freshmen students in an introduction to Agricultural Systems Management course. A survey instrument was administered to students to determine their knowledge of the elements of the diesel engine test stand and the test procedures. Before the demonstration, the students had little or no knowledge of the characteristics of a dynamometer, procedures followed for evaluating the performance and exhaust emissions of a diesel engine, and the data acquisition system. There was a significant increase in the knowledge levels on various aspects of the diesel engine test stand components and engine testing procedures. The mean difference in knowledge level before and after the demonstration of the engine test system was significantly greater than zero, indicating that the laboratory activity with the system demonstration was effective in teaching the materials and procedures of testing alternative fuels in a diesel engine.

The diesel engine test stand will be used in the testing of other alternative diesel fuels and will be demonstrated in additional courses offered in the Agricultural Systems Management curriculum. Future modifications of the engine test stand will include developing a feedback controller program for the dynamometer and making the engine test system available for remote data collection and recording over the internet.

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REFERENCES

- Agarwal, A. K. 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in Energy and Combustion Science* 33(3): 233-271.
- Anand, K., R. P. Sharma, and P. S. Mehta. 2011. Experimental investigations on combustion, performance and emissions characteristics of neat karanja biodiesel and its methanol blend in a diesel engine. *Biomass and Bioenergy* 35(1): 533-541.
- Ban-Weiss, G. A., J. Y. Chen, B. A. Buchholz, and R. W. Dibble. 2007. A numerical investigation into the anomalous slight NO_x increase when burning biodiesel; A new (old) theory. *Fuel Processing Tech.* 88(7): 659-667.
- Canakci, M. 2007. Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel. *Bioresour. Tech.* 98(6): 1167-1175.
- Coronado, C. R., J. A. de Carvalho Jr, and J. L. Silveira. 2009. Biodiesel CO_2 emissions: A comparison with the main fuels in the Brazilian market. *Fuel Processing Tech.* 90(2): 204-211.
- de Guzman, R. C., H. Tang, S. Wadumesthrige, T. Zhou, M. D. Garcia-Perez, K. Y. S. Ng, and S. O. Salley. 2010. 2009 Quality survey of retail biodiesel blends in Michigan. *Fuel* 89(12): 3662-3667.
- Dong, H., S. Shuai, R. Li, J. Wang, X. Shi, and H. He. 2008. Study of NO_x selective catalytic reduction by ethanol over $\text{Ag}/\text{Al}_2\text{O}_3$ catalyst on a HD diesel engine. *Chem. Eng. J.* 135(3): 195-201.

- Duane, A. 2008. Research and education priorities in agriculture, forestry, and energy: Achieving the 25 x '25 renewable energy vision. *Resource: Engineering & Technology for a Sustainable World* 15(7): 12-13.
- EPA (Environmental Protection Agency). 2012. Renewable fuel standard. Available at: www.epa.gov/otaq/fuels/renewablefuels/index.htm. Accessed 16 April 2012.
- Fontaras, G., G. Karavalakis, M. Kousoulidou, T. Tzamkiozis, L. Ntziachristos, E. Bakeas, S. Stournas, and Z. Samaras. 2009. Effects of biodiesel on passenger car fuel consumption, regulated and non-regulated pollutant emissions over legislated and real-world driving cycles. *Fuel* 88(9): 1608-1617.
- Ghobadian, B., H. Rahimi, A. M. Nikbakht, G. Najafi, and T. F. Yusaf. 2009. Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network. *Renewable Energy* 34(4): 976-982.
- Hess, M. A., M. J. Haas, and T. A. Foglia. 2007. Attempts to reduce NO_x exhaust emissions by using reformulated biodiesel. *Fuel Processing Tech.* 88(7): 693-699.
- Hoekman, S. K., and C. Robbins. 2012. Review of the effects of biodiesel on NO_x emissions. *Fuel Processing Tech.* 96: 237-249.
- Humburg, D. S., T. J. Hansen, L. G. Schumacher, A. K. Mahapatra, G. L. Taylor, and B. T. Adams. 2006. Biodiesel use and experience among state dot agencies. *22(2)*: 177-184.
- Lapuerta, M., O. Armas, and J. Rodríguez-Fernández. 2008a. Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science* 34(2): 198-223.
- Lapuerta, M., J. M. Herreros, L. L. Lyons, R. García-Contreras, and Y. Briceño. 2008b. Effect of the alcohol type used in the production of waste cooking oil biodiesel on diesel performance and emissions. *Fuel* 87(15-16): 3161-3169.
- Popp, M., L. Van de Velde, G. Vickery, G. Van Huylbroeck, W. Verbeke, and B. Dixon. 2009. Determinants of consumer interest in fuel economy: Lessons for strengthening the conservation argument. *Biomass and Bioenergy* 33(5): 768-778.
- Ramadhas, A. S., C. Muraleedharan, and S. Jayaraj. 2005. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy* 30(12): 1789-1800.
- Sahoo, P. K., L. M. Das, M. K. G. Babu, P. Arora, V. P. Singh, N. R. Kumar, and T. S. Varyani. 2009. Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. *Fuel* 88(9): 1698-1707.
- Schumacher, L. G., S. Soylu, J. V. Gerpen, and W. Wetherell. 2005. Fueling direct injected diesel engines with 2% biodiesel blend. *Applied Eng. in Agric.* 21(2): 149-152.
- Shi, X., X. Pang, Y. Mu, H. He, S. Shuai, J. Wang, H. Chen, and R. Li. 2006. Emission reduction potential of using ethanol-biodiesel-diesel fuel blend on a heavy-duty diesel engine. *Atmospheric Environment* 40(14): 2567-2574.
- Sorda, G., M. Banse, and C. Kemfert. 2010. An overview of biofuel policies across the world. *Energy Policy* 38(11): 6977-6988.
- Sun, J., J. A. Caton, and T. J. Jacobs. 2010. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. *Progress in Energy and Combustion Science* 36(6): 677-695.
- Van de Velde, L., W. Verbeke, M. Popp, J. Buysse, and G. Van Huylbroeck. 2009. Perceived importance of fuel characteristics and its match with consumer beliefs about biofuels in Belgium. *Energy Policy* 37(8): 3183-3193.
- Xue, J., T. E. Grift, and A. C. Hansen. 2011. Effect of biodiesel on engine performances and emissions. *Renewable and Sustainable Energy Reviews* 15(2): 1098-1116.
- Zawadzki, A., D. S. Shrestha, and B. He. 2007. Biodiesel blend level detection using ultraviolet absorption spectra. *Trans. ASABE* 50(4): 1349-1353.