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E-85 vs. regular gasoline: effects on engine performance, fuel efficiency, and exhaust emissions

Jordan W. Steinhaus, Donald M. Johnson*[†], *George W. Wardlow*[§]

ABSTRACT

This study compared the performance, fuel efficiency, and exhaust emissions of a 2.61 kW engine fueled with regular unleaded gasoline (87 octane) and an 85% ethanol blend (E85) under two load conditions. Four 1-h tests were conducted with each fuel at both governor's maximum (3400 rpm) and peak torque (2800 rpm) conditions for a total of 16 tests. At governor's maximum engine speed, there were no significant differences ($p>0.05$) between fuels for engine torque, power, specific carbon dioxide (sCO_2), specific carbon monoxide (sCO), specific hydrocarbons (sHC), or specific oxides of nitrogen (sNO_X) emissions. However, there was a significant difference in specific fuel consumption and specific dioxide (sO_2) emissions with E85 requiring the consumption of more fuel and emitting fewer oxide gases. Under peak-torque test conditions, there were significant differences by fuel for power, torque, and specific fuel consumption, as ethanol required more fuel while developing less power and torque when compared to gasoline. There were no significant differences by fuel type in sCO_2, sCO, sHC, sO_2, or sNO_X emissions. The results indicate that performance was similar when the engine was fueled by regular unleaded gasoline or E85 under rated engine-speed conditions; however, the ethanol-fueled engine produced significantly less power and torque under peak torque testing conditions. In both testing conditions, specific fuel consumption was significantly higher with E85.

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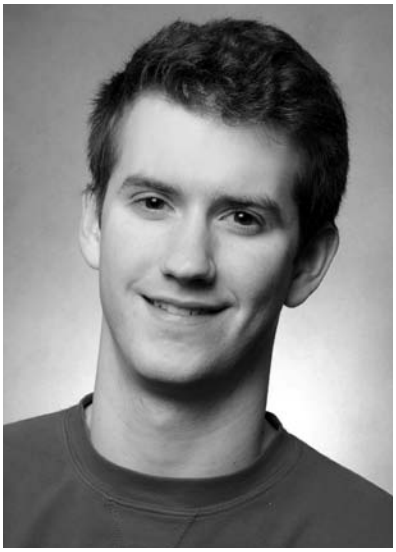

Jordan Steinhaus

I graduated from Lakeside High School in Hot Springs in 2005. In the fall of 2005, I began my undergraduate studies at the University of Arkansas through the Honors College Fellowship, Governor's Distinguished Scholarship, and the Robert C. Byrd Scholarship. During my time at the University, I have been involved with the Honors College, the First Year Experience office through ROCK Camp, Alpha Tau Alpha Honors Fraternity, the Agricultural Mechanization club as Vice President, and Lambda Chi Alpha fraternity. I am a senior majoring in agricultural systems technology management under the direction of Dr. Donald M. Johnson. I was drawn to the ASTM program due to the hands-on involvement of both the professors and their curriculum.

I began working with Dr. Donald Johnson in the agricultural and extension education department to formulate a research plan in the fall of 2007. After receiving funding for this project, we began in the spring of 2008 and have been busy ever since. I thank Dr. Johnson for his support and guidance through this past year and for the opportunity to work with him in the evaluation of an alternative fuel. Upon graduation in May of 2010, I hope to attend graduate school and continue to do research on important topics in agriculture.

INTRODUCTION

Ethanol is a renewable energy source that can be created domestically. Derived from plant matter and several grains, most popularly corn in the United States, ethanol is sometimes called grain alcohol (Houghton-Alico, 1982). Ethanol is blended with gasoline and used as a fuel in spark-ignition engines. The two most common blends available for public use are E10 (10% vol (volume) ethanol blended with 90% vol gasoline) and E85 (85% vol ethanol blended with 15% vol gasoline) (Energy, 2007). Ethanol is mixed with gasoline to help boost ethanol's lower heat energy value. Ethanol contains about 29.7 MJ/kg of fuel as opposed to gasoline's heat energy value of around 47.3 MJ/kg of fuel (Engineering, 2007). In theory, an engine would consume about 60% more ethanol than gasoline when fueling the same engine due to ethanol's lower heat value (Lincoln, 1976). However, studies have shown the lower heat values of ethanol are often offset by the fuel's high lubricant qualities, which results in the combustion of only about 15% to 25% more ethanol by volume compared to gasoline (Rothman, 1983).

Small engines produce relatively large amounts of harmful exhaust emissions. In 1991, the United States Environmental Protection Agency (EPA) estimated that small, non-road engines produced 10% of total emissions (Ross, 1999). While newer-generation engines are more efficient and more environmentally friendly, small engines still make a significant contribution to total air pollution loading.

Research has shown that lower compression ratios contribute to the production of emissions from small engines (Al-Baghdadi, 2008). Through manipulation of the compression ratio, Al-Badghdadi was able to combust E85 more efficiently, producing fewer harmful emissions when compared to testing the same engine with the manufacturer-specified compression ratio. Other researchers were able to manipulate the timing of ignition to improve emissions when fueling a small engine on an ethanol blend (Varde, et al., 2007).

The objective of this study was to determine if there were significant ($p < 0.05$) differences in power, torque, specific fuel consumption, and specific exhaust emissions of a small, single-cylinder, spark-ignition engine when fueled with E85 as compared to regular gasoline under two load conditions (governor's maximum and peak torque condition). To reflect how a typical consumer might operate the engine, no modifications were made to the engine with regard to timing or compression ratio.

MATERIALS AND METHODS

Test Fuels. Two 18.9-L (5-gallon) containers of each test fuel were obtained from The Woodshed #3 Convenience Store in Adair, Okla. A sample of each fuel was tested by Magellan Midstream Partners of Kansas City, Kan. (Table 1).

Test Equipment. The power unit for this study was a new Honda GX110 air-cooled, four-stroke, single- cylinder, spark-ignition engine (Table 2). Because a new, in-box engine was used, we performed the manufacturer's recommended engine break-in procedure prior to the experiment. Engine oil was drained and replaced after break-in was concluded.

The dynamometer used in these tests was a Land and Sea DYNOmite™ water brake absorber (N. H.) with the accompanying DynoMax© software. The power unit and dynamometer were coupled and placed on an engine stand. Dynamometer load was applied to the engine by computer-control using a servo-controlled load valve. This allowed precise and repeatable engine load and speed control.

To determine the size of carburetor jet needed for use with ethanol, we made several torque maps with different sized jets. The jet that resulted in the highest power output was deemed to be the best overall jet for the ethanol fuel. The torque maps for both fuels showed the peak torque engine rpm to be approximately 2800 and the governor's maximum to be approximately 3400 rpm.

Fuel consumption was measured on a mass basis using auxiliary fuel tanks mounted on an Ohaus SD-35™ (Ohaus, Pine Brook, N.J.) digital platform scale (35 × 0.05 kg). A separate but identical fuel tank was used for each fuel in order to avoid cross-contamination. Exhaust emissions were measured with an Auto Logic Gold 5-Gas™ (Auto Logic, Sussex, Wis.) exhaust analyzer. Exhaust manifold temperature was measured with a Raytec AutoPro ST25™ (Raytec, Santa Cruz, Cal.) non-contact infrared thermometer (-32 to 535°C at 1% accuracy) (Fig. 1).

Methods. The order of testing was held in sets of four, 1-h tests as determined randomly. Both fuels were tested under 2 load conditions (governor's maximum and peak torque) with four replications of each level of fuel and load (16 total tests). Before each test, barometric pressure, temperature, relative humidity, and fuel mass were recorded. During the tests, data were manually recorded data every 5 min. Data were collected on fuel mass, power, torque, rpm, exhaust manifold temperature, and specific carbon dioxide (sCO_2), specific carbon monoxide (sCO), specific hydrocarbons (sHC), specific dioxide (sO_2), and specific oxides of nitrogen (sNO_X). The emissions analyzer automatically logged data throughout the duration of the test at 1-s intervals. To switch to a different fuel, the appropriate carburetor jet was installed, the tank was switched and all remaining fuel in the lines and engine was purged.

Test Conditions. All testing was conducted in open-air conditions. To control for differences in ambient conditions, the temperature, barometric pressure, and relative humidity during each test were recorded and used to determine power and torque correction factors (Shelquist, 2009). Subsequent analyses were conducted using corrected power and torque values. Data were analyzed using descriptive statistics and analysis of variance (ANOVA) procedures.

RESULTS AND DISCUSSION

Governor's Maximum Speed. At the 3400 RPM governor's maximum speed, there were no significant differences by fuel for engine torque ($P = 0.37$) or power ($P = 0.41$). There was a significant difference in specific fuel consumption ($P < .0001$) by fuel. When fueled with E85, the engine required 50% more fuel to make almost identical power.

There were no significant differences between fuels in sCO_2 ($P = 0.24$), sCO ($P = 0.22$), sHC ($P = 0.37$), or sNO_X ($P = 0.10$) emissions. Fueling with E85 resulted in significantly lower ($P = 0.03$) sO_2 emissions, with E85 reduced sO_2 emissions by 12.9% compared to regular gasoline (Table 3).

Peak Torque. For peak torque testing (2800 engine RPM), there were significant differences by fuel for engine power ($P = 0.01$) and torque ($P = 0.04$). When compared to regular unleaded gasoline, fueling with E85 decreased engine torque and power by 21.9% and 24.7%, respectively. Fueling with E85 resulted in significantly higher (124%, $P < 0.0001$) specific fuel consumption than did fueling with regular gasoline. There were no significant differences by fuel in sCO_2 ($P = 0.34$), sCO ($P = 0.30$), sHC ($P = 0.053$), sO_2 ($P = 0.88$), or sNO_X ($P = 0.63$) emissions (Table 4).

When fueled with E85, specific fuel consumption was significantly higher when compared to regular unleaded gasoline. This was expected due to ethanol having a lower heat-energy value compared to regular unleaded gasoline. This is somewhat consistent with other research (Al-Baghdadi, Gautam et al.); however, the results shown in this testing indicate far greater fuel consumption by the engine fueled with E85 than other researchers have reported. This may be due to incomplete combustion, especially under peak-torque load, as the carburetor jet was sized to maximize power, not efficiency. Additionally, carburetors have been shown to be less efficient in atomizing ethanol (Al-Baghdadi, 2008) especially at the high flow rates that the engine needs, causing peak torque consumption to trend much higher. Further research is recommended to determine the cause of this finding.

There were no significant differences in torque or power between E85 and regular gasoline at governor's maximum. Although E85 has a lower heat-energy value, the consumption of more E85 offset the energy difference. However, under peak torque conditions, torque decreased by 21.9% and power decreased by 24.7% when fueled with E85 relative to regular gasoline. This difference between regular gasoline and E85 is again inconsistent with what other studies have shown (Al-Baghdadi, Gautam et al.).

After talking with several researchers, the cause of this discrepancy is still not understood. Therefore, more deliberation and study are suggested.

When compared to regular unleaded gasoline, E85 produced no significant reduction in emissions with the exception of decreasing sO_2 emissions by 12.9 per cent under rated speed conditions. It should be noted that all emissions did trend lower when the engine was fueled with E85 but not enough for a significant difference to be found. Other studies (Al-Baghdadi, 2008; Hull, et al., 2006; He, et al., 2003; Varde, et al., 2007; Agarwal, 2007) found a reduction in emissions to some extent, with most reporting significant reductions in CO, CO_2, and NO_X. Though all steps were followed in preparing the emissions analyzer correctly, the data exhibited a large degree of variance. The analyzer may be the root of the discrepancy between the results of this study and others. In future research, a laboratory-grade analyzer should be used instead of the garage-grade analyzer used in this study.

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Table 1. Physical and chemical properties of regular unleaded gasoline and E85.

Fuel property	ASTM test no.	Reg. unleaded	E85
Density (g/ml)	4052	0.7432	0.7798
Heat of combustion (MJ/kg)	240	45.65	35.25
Purity	---------	---------	75.62% vol. ethanol 0.37% vol. methanol

*Note: Analysis by Magellan Midstream Partners, L.P., Kansas City, Kan.

Table 2. Honda GX110 engine specifications.

Bore	57mm
Stroke	42mm
Displacement	107 cc
Rated power	2.61 kW @ 3600 rpm
Rated torque	0.7 kg-m @ 2800 rpm

Table 3. Power, torque, specific fuel consumption, and emissions at governor's maximum (3400 RPM).

	Reg. Unleaded		E85	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Power (kW)	2.06	0.106	2.11	0.076
Torque (Nm)	5.85	0.347	6.05	0.232
Sfc* (kg/kWh)	0.38	0.018	0.57	0.036
sCO_2 (ppm/kW)	4.24	1.089	3.54	0.096
sCO (ppm/kW)	2.11	0.798	2.73	0.422
sHC (ppm/kW)	289.71	408.799	91.51	11.017
sO_2 (ppm/kW)	2.90	0.266	2.52	0.070
sNOx (ppm/kW)	238.27	180.928	60.19	24.847

*Specific fuel consumption

Table 4. Power, torque, specific fuel consumption, and emissions at peak torque speed (2800 RPM).

	Reg. Unleaded		E85	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Power (kW)	2.04	0.243	1.54	0.155
Torque (Nm)	6.84	1.024	5.34	0.494
Sfc (kg/kWh)	0.30	0.088	0.67	0.127
sCO_2 (ppm/kW)	3.84	0.575	4.49	0.918
sCO (ppm/kW)	1.69	0.368	2.39	0.979
sHC (ppm/kW)	86.48	16.029	136.88	31.170
sO_2 (ppm/kW)	3.43	0.531	3.56	1.379
sNOx (ppm/kW)	258.61	48.031	189.78	222.977

*Specific fuel consumption

Fig. 1. Experimental setup for fuel testing.