

Retrofit of a Briggs & Stratton Small Engine to Run E85

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Abstract

A Briggs and Stratton carbureted small engine was retrofitted to use E85 (85% ethanol and 15% gasoline) for fuel. The feasibility of retrofitting a Briggs & Stratton Quantum ® 5.75 horsepower lawnmower engine to run on E85 fuel was examined. The problems with running high ethanol content fuels were identified to be: possible material compatibility issues with the ethanol, lowered air to fuel ratio, and possible cold start problems. A method for overcoming these difficulties is presented and it was determined that a simple retrofit could be performed by modifying the carburetor to increase fuel delivery. Testing the fuel to air ratio was accomplished by the creation of an analytic muffler with an integrated O₂ sensor and thermocouple. The lawnmower performed excellently in long term tests, lasting two months, being run for up to two hours at a time. Fuel consumption was not significantly increased and the results of fuel consumption tests for an E85 converted carburetor running a lean mixture is comparable to that of a normal gasoline burning lawnmower. The results of the mowing were analyzed and it was determined that the E85 caused no discernable damage over the length of testing performed. Future testing is also discussed.

Keywords: E85, Alcohol fuel, Alternative fuels, Biofuels, Ethanol, Retrofit, Small Engine.

1. Introduction

The world is at the brink of a fossil fuel crisis. Alternative fuels need to be implemented in every application possible and the best place to start is with domestically produced bio-fuels such as biodiesel and bio-ethanol. In small, four cycle, lawn and garden equipment the natural choice is ethanol fuel, E85 in particular, which is a mixture of 15 percent gasoline and 85 percent ethanol.

Unlike other alternative fuels such as hydrogen, E85 is currently available and is compatible with only minor modifications in current four-cycle internal combustion engines. E85 has many advantages over regular gasoline. The main constituent of E85, ethanol, is produced from domestically grown renewable resources, mostly corn, which helps against dependence on foreign oil sources. It has been established that E85 produces fewer harmful emissions^{1,2} than regular gasoline including reduced oxides of sulfur, less volatile compounds, and a drastic reduction in hydrocarbon emissions. With ethanol, the carbon released during combustion is recycled back into new plants being grown to produce more ethanol as part of the carbon cycle¹. Ethanol also has a positive energy balance² of 5% to 35% depending on the method of production which means that the ethanol contains more energy than is required to produce it since the bulk of the energy required to grow the plants is provided by the sun. Gasoline on the other hand has a negative energy balance of around 14% referred to as an embedded cost in the petroleum industry. This means that on average 18 ounces of gasoline must be consumed to produce a gallon of gasoline.

Despite the amount of attention being paid to alternative fuels in automobiles, not much research is being done in the area of ethanol and small engines. The SAE Supermilage³ competition allows ethanol or E85 to

be run in the competition, but as of yet no manufacturer has made any public announcements to develop or produce E85 compatible lawn and garden equipment.

Much research has already been completed on running both automobile and aviation engines on E85 and provides a solid knowledge base for this project. Automobile manufacturers such as GM, Daimler Chrysler, Ford, Mazda and others have already made a switch to producing some Flexible Fuel Vehicles (FFV)³. FFV's are gasoline burning engines that have ethanol sensitive materials replaced with more durable components and a fuel control computer installed that detects the amount of ethanol in the fuel and adjusts the engine so that they may run anywhere from 0% ethanol up to 85% ethanol. In the aerospace sector ethanol is especially promising due to ethanol's high octane rating. Baylor researchers Drs. M.E Shauck and M.G Zanin have even be awarded FAA certification to fly a Cessna 152 on 100% ethanol⁴ and a Dual Fuel conversion of carbureted Cessna Engine has been completed by Drs. Loth, Bond, and Lyons at West Virginia University⁵

The research of Shauck and Zanin, as well as Loth, Bond and Lyons has shown that aluminum engines with elastomer fuel components are subject to damage from corrosive ethanol^{4,5}. A carbureted lawnmower could be made ethanol friendly using a similar procedure used on carbureted airplane engines. In the dual fuel experiments the aluminum fuel tanks had to be alodized (a process similar to anodizing) to prevent corrosion and the aluminum fuel lines had to be replaced with stainless steel. The dual fuel system had an extra fuel pump that delivered the required amount of ethanol fuel to the engines so carburetor functioning did not have to be modified. All natural rubbers and incompatible polymers had to be exchanged with compatible ones such as viton and high-density polyethylene (HDPE). Ethanol fuels have a tendency to be hard to start in cold weather but the addition of petroleum fuel eliminates this problem in all but the most extreme cases.

2. Methodology

As mentioned before, there appear to be four major problems with using E85 as a fuel in lawn mowers which must be overcome during the retrofit. First is that ethanol is a strong solvent and can be very corrosive to natural rubbers, some polymers and some metals^{4,5}. Components of the mower that come into contact with the ethanol rich fuel have to be examined on both a predictive basis of material selection and the during the practical application of running the engine to determine which components of the engine needed to be modified or replaced with more suitable materials. Secondly E85 has different combustion characteristics than gasoline alone. The carburetor has to be modified to allow for the required fuel flow rate based on calculations and experimental data. The third problem is that ethanol has a higher octane than pump gasoline. To run efficiently a higher compression ratio is required. And fourth is that Ethanol has a higher vapor pressure than gasoline which means there may be cold starting problems that must be taken into account. These problems were examined and the following methodology is presented for overcoming these problems along with the procedures used for testing the effectiveness of the solution.

2.1. retrofit

The lawnmower used for testing would not run on E85 without any modifications. To retrofit the lawnmower to run this fuel the materials that come into contact with the fuel had to be identified to make sure that no material will degrade so fast as to prevent the lawnmower from running. The correct air to fuel ratio for E85 needed to sustain combustion had to be compensated for by either changing the amount of air or the amount of fuel coming into the engine. Any cold start problems had to be corrected for and the low compression ratio of the stock lawnmower will have to be examined to avoid problems.

The materials that come into contact with the fuel can be identified using the parts list provided by Briggs and Stratton and available for every engine that they produce⁶. The material of each component was identified using these parts lists and materials compatibility charts was used to predict material compatibility with pure ethanol. A predictive materials compatibility chart was created using material property data sheets^{7,8} and it was determined that no component in the fuel path would degrade so rapidly as to prevent the lawnmower from being used at least over a short testing period lasting one summer. To help identify material compatibility problems, no material was replaced to allow for long term, in mower testing.

The most important step in the retrofitting process was to alter the air to fuel ratio. In a carbureted engine this is easiest to do by modifying the carburetor to change the amount of fuel coming into the engine and leaving the amount of air intake fixed. The part of the carburetor that does the most to govern fuel flow is the diameter of the main jet. The natural vacuum of the carburetor pulls the fuel through the main jet and the amount of fuel pulled is directly related to the size of the main jet. The

The fuel to air ratio had to be corrected before the mower would run. The E85 used for testing was obtained from BP which consisted of 82.5% ethanol and 17.5% gasoline⁹. Ethanol contains less energy than gasoline measured as the specific calorific value. While gasoline contains 42 MJ/kg, ethanol only contains 27 MJ/kg or 64% of the energy of gasoline. Gasoline needs more air to burn at stoichimetric ratio than ethanol which means for a given amount of intake air, more E85 will have to be burned than gasoline. The required increase in fuel can be calculated knowing that the density of gasoline¹⁰ ranges between 0.720 kg/l and 0.775kg/l for an average of 0.7475 kg/l. It can be shown that the diameter of the new main jet is a function of the original diameter and the concentration of ethanol of the fuel as seen in equation (1) below

$$D = 3.75 \sqrt{\frac{D_o^2}{14.7 - 5.7\epsilon}} \quad (1)$$

where D is the size of the new diameter, Do is the original diameter and ε is the concentration of ethanol in the fuel. Applying equation (1) we find that a 0.027” jet will have to be increased to 0.032”. In other words almost a 16% increase in diameter results in the required 40% increase in fuel flow.

The enlargement was carried out by clamping of the fuel line, removing the main jet from the bottom to the carburetor, using the appropriate wire gauge drill bit from the Irwin set to drill out the nozzle and replacing the jet. Figure 1 below shows the working E85 mower and test equipment.



Figure 1) Test Setup of Lawn Mower.

Figure 1 The test mower with testing equipment shown.

2.1.2. end of year procedure

Briggs & Stratton normally recommends an end of season procedure to store their lawn mowers. Due to the corrosive nature of the E85 fuel additions should be made to this list and the procedure becomes a must to prevent unnecessary damage to the mower. The revised procedure is as follows and is based on Briggs & Stratton's manual and Walbro's suggestions regarding high levels of ethanol and carburetors ^{7,11}.

1. Run engine until it runs out of fuel.
2. Add small amount of regular gasoline and run again until out of fuel.
3. Change oil while engine is still warm.
4. Remove spark plug and add ½ ounce of oil into cylinder. Replace spark plug to distribute oil.
5. Clean mower.
6. Store in clean dry area.

2.2. testing

The following sections present the methodology for testing the outcome of the retrofit including more materials compatibility testing, air to fuel ratio analysis, and fuel consumption.

2.2.1. materials compatibility

One of the major concerns of the project was the compatibility of materials used in construction of the lawn mower engine with the high levels of ethanol in the E85. Most lawnmowers, including the Quantum engine used in testing, have engines made primarily of aluminum to which ethanol is notoriously corrosive. Also, many of the gaskets, seals and other rubber or plastic components may also be susceptible to damage from exposure to ethanol levels above 10%. Briggs & Stratton motor company issues a warning in their manuals against using concentrations of ethanol over 10%⁷ and the Walbro Company, the manufacturer of the carburetor used, corresponded a similar warning of using concentrations higher than 37%¹²

To test those components suspected of failing, a predictive chart was created and critical components were examined before and after the project. For the components predicted to be susceptible to corrosion a submersion test was performed in soda glass jars with Teflon coated lids that are ethanol proof. The parts tested in the long term exposure test were an aluminum cylinder head submersed for two months, a steel intake valve, a steel exhaust valve, and a carburetor float each submersed for one month.

Table 1. materials compatibility chart for test lawnmower

Part	Material	Predicted Compatibility	Experimental Compatibility	Replace in Retrofit Kit
Fuel Tank	HDPE	YES	YES	No
Fuel Line	Neoprene	YES	YES	NO
Fuel Bowl	Aluminum	NO	YES	NO
Float	Plastic	NO	NO	YES
Pedestal	Aluminum	NO	YES	NO
Main Jet	Brass	YES	YES	Jet Size-changed
Fuel Nozzle	Brass	YES	YES	NO
Throttle Plate	Steel	YES	YES	NO
Throttle Shaft	Steel	YES	YES	NO
Throttle Plate	Aluminum	NO	YES	NO
Intake Valve	Steel	YES	YES	NO
Exhaust Valve	Steel	YES	YES	NO
Piston	Aluminum	NO	YES	NO
Intake Port	Aluminum	NO	YES	NO
Exhaust Port	Aluminum	NO	YES	NO

2.2.2. carburetor functioning

The calculations used to determine the correct air to fuel ratio for the E85 needed to be verified. Two custom mufflers containing automobile O₂ sensors, also called E.G.O (exhaust gas oxygen) sensors or lambda sensors, were fabricated and used to test the level of oxygen in the exhaust gas. O₂ sensors are used in automobiles to control the air/fuel mixture by using a solid state electrolyte that at high temperatures generates an electromotive force based on how much oxygen is in the exhaust compared to the oxygen content of the incoming air¹². The sensors employed were heated units used to speed up the ability of the sensor to take readings. To be able to take exhaust temperature measurements a thermocouple port was also installed in the EGO muffler.

A Craftsmen Autoranging Multimeter, model number 82028, using k-type thermocouple attachments was used to read the thermocouple and O₂ sensor output. Both a Craftsmen OEM k type thermocouple and an Omega HKMQSS-125G-6 k type thermocouple were used to measure the exhaust temperature. When the mixture is at the correct air to fuel ratio the sensor will produce 0.500 V, 1.00 V when rich and 0.00 V when lean. Figure 2 below shows a CAD rendering of the muffler that was designed for this use. The muffler was constructed by the machine shop staff at the University of Tennessee. The EGO muffler with all attachments including the leads from the O₂ sensor that were run to the multimeter and the battery to power the resistance heater can be seen in figure below.

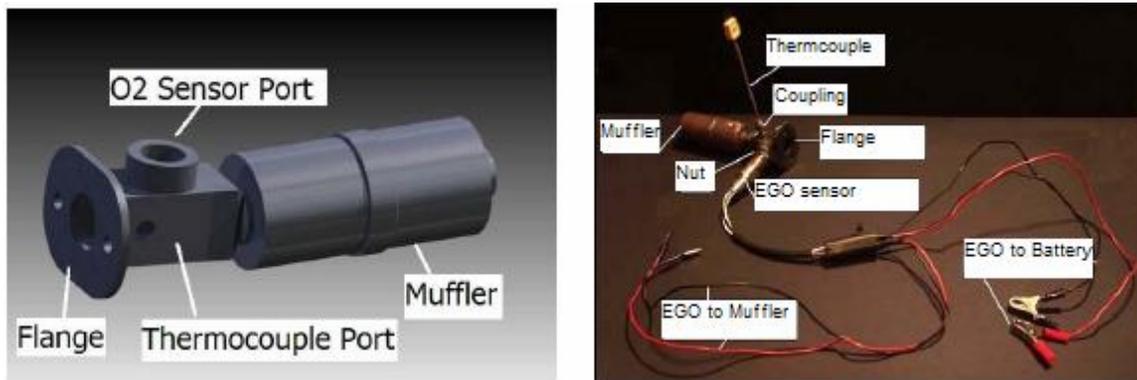


Figure 2. CAD rendering of EGO muffler and photograph of EGO muffler with attachments

Figure 2. The left hand CAD rendering of base muffler design with O₂ sensor port and thermocouple ports shown. The flange bolts onto the mower's exhaust port. The tube muffler is used to quiet the engine during testing. The right hand side shows the Ford E.G.O. sensor with custom built muffler and sensor to battery and sensor to multimeter connections labeled.

2.2.3. fuel economy

Fuel economy was tested by measuring 300ml of fuel at a time using a Pyrex ® beaker and using a stop watch to measure the time to use the fuel at full throttle. The tests were all ran in the same position with no load applied to the mower. This is a very rudimentary method of testing but allowed some reference of rate of fuel consumption compared to that of gasoline.

3. Data

The following sections present the results of the testing methods described previously.

3.1. materials

The results of long term testing lasting 60 days showed no discernable damage to the aluminum cylinder head, steel intake valve or steel exhaust valve which is great news since it could mean that a coating process is not needed on the aluminum parts or the steel parts, but of course longer testing will be needed to confirm this. The unknown type of plastic used to make the carburetor float however showed some oxidation and discoloration. No swelling was seen, but a new material for the float may have to be substituted. The internal seals of the carburetor held up to testing, but were not identifiable and according to the Walbro Company, should be replaced in a thorough retrofit.

It appears that most of these materials would stand up to the ethanol if the engine was flushed with pump gasoline at the end of the season. In section 2.1.2 entitled “End of the Year Procedure” instructions were given for preparing the engine to sit for long periods of time given the special needs of materials in contact with such high levels of ethanol.

3.2. fuel to air ratio

Both lambda units were attached to the mower and the voltage from the lambda sensor, the exhaust temperature, and the RPM of the engine were recorded. Table 2 shows the progression of the testing. To test, the sensors were attached and the engine was started and allowed to come to operating temperatures above 1000 degrees F according to the thermocouple. An initial reading was taken. If the initial reading was not 0.500 Volts, the primer bulb was pushed and the voltage jumped from the initial value to 1 Volt. It was therefore very easy to confirm that the engine was initially running lean.

The OEM main jet did not allow enough fuel flow to run the Quantum engine. To increase the draft of the carburetor, an angle was cut on the fuel nozzle of the carburetor. This slight adjustment allowed the engine to run albeit very poorly. The main jet was then drilled out to the calculated thirty two thousandths of an inch. The correct fuel delivery allowed the mower to function as it would with regular gasoline. The E.G.O muffler read right at 0.500 V and jumped up and down from high to low voltage which the Bosch handbook said would occur at the stoichiometric ratio¹².

Even when the mixture is correct, slight acetaldehyde smell occasionally accompanies the combustion at stoichiometric levels. To get a dual fuel capable mower the smallest jet diameter possible of 0.028 inches was installed and the mower ran on both fuels reasonable well. In fact the acetaldehyde smell was completely eliminated at such lean mixtures. Leaner mixtures will be possible once the compression ratio is raised to a level more suitable to the higher octane rating. Table 2 below shows the voltage readout of the multimeter from the O₂ sensor and the results of the test as a function of the jet diameter.

Table 2. Comparison of nozzle size to fuel to air ratio operating on E85

Setup	Nozzle angle	Jet diameter	Voltage	Lean/Rich	Run Notes
1	Flat	.0270 in (OEM)	0.00	Too Lean	Would not run
2	Slight	.0270 in	0.00	Lean	Barely runs
3	Slight	.0280 in	0.300	Lean	Runs good
4	Slight	.0320 in	0.500	Correct	Runs great, acetaldehyde smell

3.3. fuel economy

The E85 got 17 % better fuel economy in the 0.028 inch jet than gasoline perhaps due to the increased density of the E85 making the fuel flow rate slower. More tests with using established methods are needed to confirm this assumption. With the 0.032 inch jet the E85 got fewer minutes per 0.300 liters but the gasoline ran so rich the tests were stopped for fear of fowling out the plug. Table 3 presents the results of the measured fuel consumption rates with the various jet sizes used with E85 and with gasoline.

Table 3. Fuel consumption based on fuel and main jet diameter

Main Jet Diameter	Fuel	Flow rate	Description	Run notes
0.027 inch	Gasoline	0.00440 Gal/min	Original size	Runs great
0.027 inch	E85	NA	Original size	Will not run
0.028 inch	Gasoline	0.00440 Gal/min	Min. size for dual	Runs good
0.028 inch	E85	0.00377 Gal/min	Min. size for dual	Runs good
0.032 inch	Gasoline	NA	Calculated for E85	Will not run
0.032 inch	E85	0.00396 Gal/min	Calculated for E85	Runs great

3.4. cold starting problems

Ethanol is notorious for cold starting problems and much research on the subject has been completed such as that of Hodgeson and Irick.^{13,14} The low Reid Vapor Pressure of the Ethanol results in cold starting problems in temperatures less than 65 degrees Fahrenheit.¹³ Adding the 15% gasoline to the ethanol removes most of the cold starting problems that neat alcohol experiences, but with the lower compression ratio of the Quantum engine it is not known at what temperature cold starting problems will occur. The testing of the mower was conducted during the summer in East Tennessee which proves very troublesome when trying to get temperatures below sixty five degrees Fahrenheit. Additional testing later in the year will prove to be more useful for further study.

3.5. compression ratio

The E85 provides many additional benefits such as a higher octane number which boosts performance capabilities. Ethanol has an octane number of 112¹² and most gasoline does not have more than a 93¹² octane number even with octane boosters currently used. Due to E85 having a higher octane rating than gasoline alone, the compression ratio should be raised to realize the performance potential of the E85. Previous research, especially in Brazil¹⁴, testing of a Volkswagen engine with pure ethanol shows the incredible performance gains from increasing the compression ratio. Engine tests were run at a compression ratio of 7.2:1 and then at 11:1. Horsepower increased by 18.7%, torque increased by 20.5% and energy savings of up to 30% were also seen¹⁴. When using the cold-air assumption that intake air is at 25 degrees Celsius, an Ideal Otto cycle depends on the compression ratio and the specific heat ratio of the intake air¹⁰. The dramatic effect the compression ratio has on raising the thermal efficiency is seen better in equation (2)

$$\eta_{TH} = 1 - \frac{1}{r^{k-1}} \quad (2)$$

where the maximum efficiency is 1 and r is the compression ratio and k is the specific heat ratio of the working fluid which can be modeled as atmospheric air¹⁰. Since r is in the denominator and the exponent term is constant the larger the compression ratio gets the closer the thermal efficiency gets to its maximum.

4. Conclusion

The project was a success. A simple retrofit of a Briggs and Stratton powered lawnmower can be completed by applying the nozzle diameter equation presented to make the modifications to the carburetor to account for the extra fuel requirements. The original equipment held up to the corrosive fuel for the duration of testing, with only the carburetor float showing any signs of reaction to the E85. There were no cold start problems during testing. The compression ratio of the stock mower was sufficient for running the lawnmower under high, wet grass conditions, the mowing situation that requires the most power from the engine. The lean mixture nozzle diameter allowed mowing for the summer season of 60 days and over 13

hours of testing. The lean mixture also eliminated the sensible production of acetaldehyde, the emissions component that caused the most concern.

This study should establish that alternative fuels have a future in lawn and garden equipment. The future of this project involves a thorough retrofit of the lawnmower by replacing all ethanol sensitive materials in the fuel path with resistant materials. To realize the full performance potential of the higher octane fuel, the compression ratio of the lawnmower must be raised. This will increase the efficiency of combustion as well as increase the power output of the engine. The engine timing will have to be examined when raising the compression ratio to avoid any engine knock that may result when running gasoline in the engine for the end of the year procedure. The emissions of the lawnmower could be different than an automobile engine as single cylinder small engines do not have the advanced control systems, but neither does a Cessna engine⁵, and as such must be investigated. A combustion catalyst for the prevention of acetaldehyde could be research and implemented on top of lean burn studies with the small engines. Finally the results of this and similar studies should be presented to the manufacturers of small engines to encourage their interest in alternative or dual fuel lawn and garden equipment. The first phase of ethanol compatible small engines would have to be dual fuel since E85 is not available in all areas but is rapidly being implemented across the US and other parts of world.

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