Minnesota Center for Automotive Research

Briggs & Stratton 5.25 Redo Final Report 11-6-14)

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RE Briggs & Stratton 5.25 Redo – Final Report

Final Conclusions

This study examined twelve Briggs & Stratton 5.25 engines and four different ethanol fuel concentrations; E0, E10, E15, and E20. All twelve of the engines, regardless of fuel, lasted through the 125 hour emissions determination period (EDP). One engine running on E10 experienced a large drop in compression due to the cylinder walls becoming scored, but the root cause of the scoring could not be determined. The largest influence during the study appeared to be the rich to lean air fuel ratio manufacturing variance of the engines which was used for the fuel assignment. The richest operating engines received E0 while the leanest operating engines received E20. Since all of the engines received baseline testing on E0 first, before running on a blended fuel, the initial change in performance caused by switching the fuel could be measured. Also, at the end of the study all of the engines were again switched back to E0 to measure changes caused by the fuel.

The ethanol blends (E10, E15, and E20) did not increase engine wear or deposits in the engines. No fuel system material compatibility issues, corrosion or deposits, were discovered during the testing. The ethanol blends did not have an effect on starting or hot restart/ vapor lock. There were no difference in terms of oil contamination between the blends and E0. There was however a difference in oil consumption. The E15 engines on average consumed 33% more oil than E0, while the E10 and E20 engines consumed 20% less oil than E0. It was also noted at the beginning of the study, that the E15 engines on average had 5% higher oil, exhaust gas, and cylinder head temperatures.

In terms of horsepower and torque output, the rich to lean manufacturing variance of the engines had the largest influence. Switching from E0 to the blends changed the output very little. However, E20 did increase the amount of initial RPM drop when a load was applied at the beginning of the study. By the end of the study the engines acted similarly in terms of load pick-up. Overall by the end of the study, the engines operated very similarly to each other regardless of fuel in most properties except emissions.

The largest difference found during the study was the change in emissions. The higher the ethanol blend, the greater the decrease in carbon monoxide. E15 and E20 decrease carbon monoxide emissions by 33% and 35% respectively. However, E15 and E20 increase oxides of nitrogen emissions by 57% and 37% respectively. Hydrocarbon emissions were also influenced. E0 and E10 exhibited an increase in hydrocarbon emissions throughout the testing while E15 and E20 showed a decrease throughout the testing.

Many of the differences seen throughout the study were a result of enleanment of the air fuel ratio. This could be seen in the manufacturing variation and from the increase in ethanol. E15 in general caused the greatest change in the engines, even more than E20. This is most likely due to the fact that the engines that E20 was tested in were already leaner than the others, and the addition of E20 caused enleanment to the point that temperatures lowered when compared to E15. By the end of the study, after the all of the engines had accumulated 125hrs, most of the differences were gone between the fuels and the engines performed similarly.

The increase in ethanol concentration from E10 up to E15 or E20 will most likely cause some issues with small engine. Based on the study, the issues seen were due to enleanment. Other than enleanment, E15 and E20 did not seem to cause any additional problems. If the carburetors were set to a richer mixture this could be eliminated, but at a richer mixture the engines might not pass emission if tested on E0. Also, if an engine is already experiencing enleanment due to a variety of factors such as carburetor gumming or cold temperature operation, the additional enleanment from the fuel could be enough to cause operational issues.

Study Overview

The purpose of this study was to determine the durability, wear, emissions, performance, and reliability of small non-handheld gasoline engines running on E0, E10, E15, and E20. E10 being 90% gasoline and 10% fuel grade ethanol by volume. Small non-road engines (SNREs) typically use carbureted fuel systems which are unable to adapt to different fuel compositions like modern automobile engines can. SNREs are also generally produced at a lower cost and have a shorter expected life span than an automobile engine. Due to factors such as these, there is a lot of concern with increasing the ethanol concentration at the pump.

The Briggs & Stratton 5.25 engine was selected for this study to represent the older technology engines that are still in service in a variety of equipment. This engine is an L-head design which means that the valves are located in the block instead of the cylinder head. This is an inefficient design, but allows the engine to be manufactured at a low cost for light duty consumer grade products. Consumer grade equipment (125-hour Emission Determination Period, EDP) is manufactured with lower cost materials and designs because they are not made to be used as much as commercial or industrial equipment (1000-hour EDP). Fuel and wear related issues are more likely to show up in these lower cost engines. This study used 12 engines, each run on one of the four fuels; gasoline (E0), E10, E15, and E20 (3 engines X 4 fuels =12 engines total).

For the study, engines were first broken-in for 5-hours running on E0 to ensure they all work correctly. During break-in and aging, the engines were coupled to an electric generator head to provide load (Figure 1). The electricity generated in the process was dissipated via heat from two resistive heaters connected to the switch box as shown in Figure 2. This provides an accurate reliable method of loading multiple engines for extended periods of time. A repetitive cycle consisting of 2-minutes at idle, 2-minutes at full load, and 6-minutes at approximately half load was used for break-in and aging. After break-in, the engines followed the testing sequence shown in Figure 3.

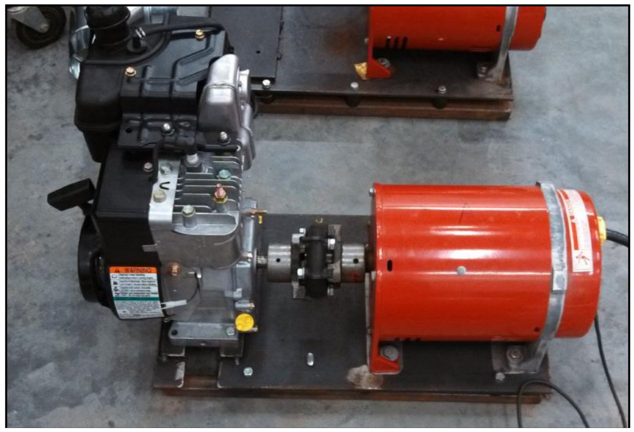

Figure 1 Engine coupled to generator head for loading

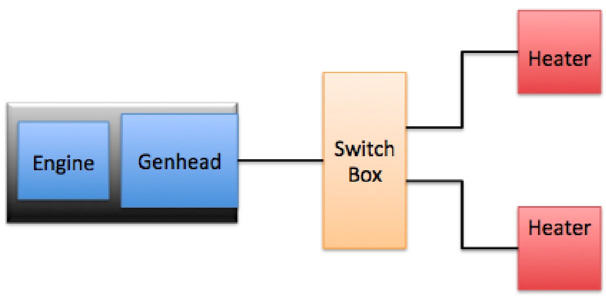

Figure 2 Diagram of testing apparatus used for break-in and aging

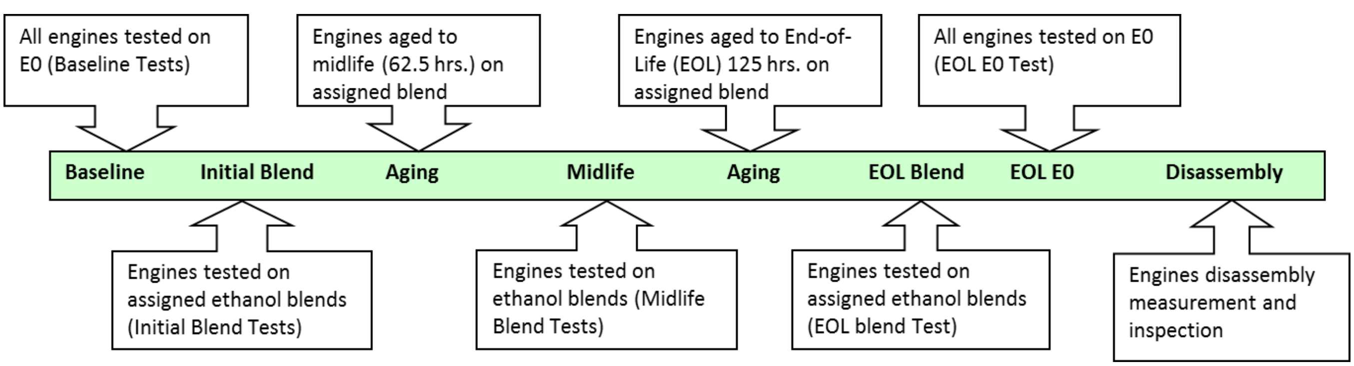

Figure 3 Testing sequence used during the study

The following performance tests were run on E0 to provide a baseline (baseline tests) and midlife and at the end of the EDP.

- Starting
- Hot restart/ vapor lock
- Idle/ rated speed stability
- Acceleration / load pickup
- Exhaust/ cylinder head/ oil temperature
- Emissions (on Dynamometer Figure 4)
- Maximum power/ torque output (on Dynamometer)

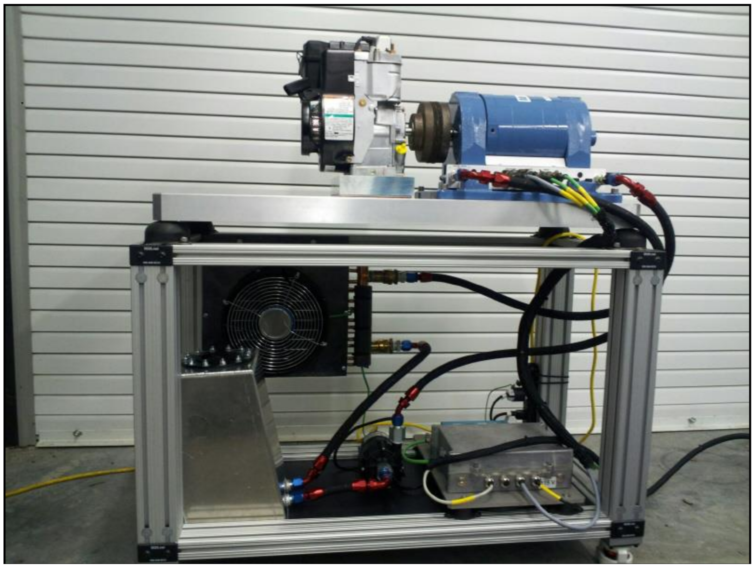

Figure 4 Engine mounted to the dynamometer for horsepower, torque and emissions measurements

After the baseline set of tests were performed, the engines were assigned their specific blend based on a rich to lean order. The richest operating three engines were assigned E0 and the leanest operating three engines were assigned E20 to pronounce any effects from the fuel. The tests were again performed with the engines running on their assigned blend (initial blend tests). After the initial blend tests the engines were aged on their assigned blend to their midlife, 62.5-hours, and then the same performance tests were conducted again (midlife blend tests, on assigned blend). Next, they were aged until their rated EDP of 125-hours where the performance tests were conducted two more times, once on their assigned blend (end-of-life blend test) and once with all the engines running on E0 (end-of-life E0 tests). Note, for this paper EDP and end-of-life (EOL) will refer to tests conducted after the 125-hour EDP period was reached. Finally, at the end of the study the engines were disassembled and internal components were measured for wear and inspected for any other issues.

The fuel used for the study was splash blended to obtain the specific concentrations for the testing. The ethanol was obtained from a local plant and was denatured with 5% gasoline. Eight different fuels were used during the study. Fuels for break-in, aging, starting and load pick-up tests were splash blended with a locally obtained non-oxygenated pump fuel. During emissions, power, and torque measurements, Tier 2 EEE reference fuel blended with ethanol was used.

Throughout the study the engine manufacturer's maintenance schedule was followed. The engines were equipped with hour meters to monitor run-time on the engine and thermocouples to measure crankcase oil, cylinder head, exhaust gas, and intake air temperatures. The crankcase oil was monitored for consumption and contaminants. The fuel system was also monitored for any signs of material compatibility issues. The engines compression was measured after break-in, midlife, and at the end-of-life.

Tests and Results

All of the engines, regardless of fuel type, completed the 125 hour EDP and the two EOL performance test regiments. There were several differences noted between engines running on E0 and engines running on an ethanol blend as discussed below.

Oil Consumption and Contaminant Analysis

The oil from each engine was sent out for contaminate analysis at 5, 55, 105, and 130 hours. The analysis checked for fuel, soot, water, wear metals, contaminate metals, additive metals along with oil properties. The oil analysis results were very similar regardless of fuel. None of the samples were rated as critical in terms of contaminates or wear metals. The most common property rated at "abnormal" was the viscosity, but this was not at a level requiring an oil change.

The oil consumption of the engines was measured by weighing the oil into the engine and the oil removed from the engine (Figure 5). Overall, oil consumption was greatest for the engines running on E15, 33% greater than the engines running on E0, while the engines running on E10 and E20 consumed 21% and 20% respectively, less oil than did E0.

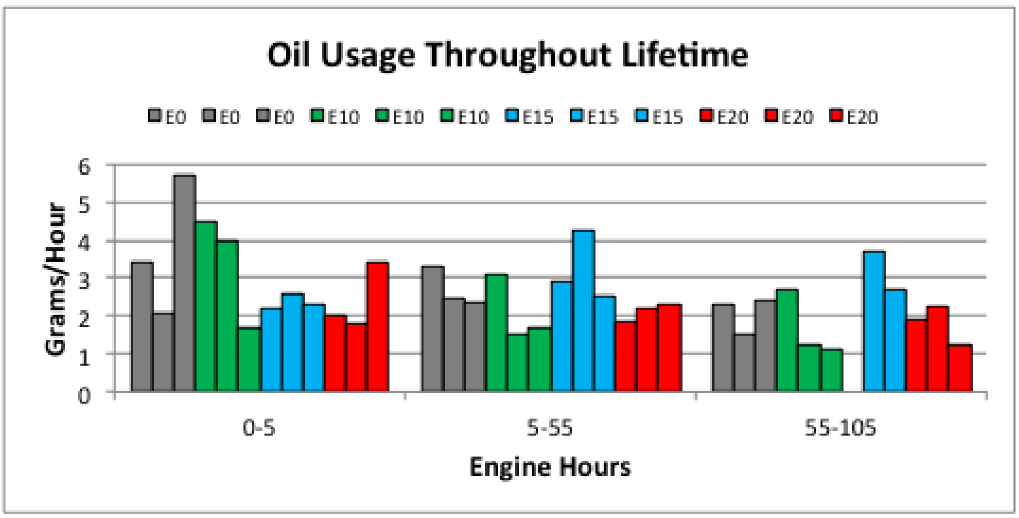

Figure 5 Oil consumption in grams per hour

Starting and Hot Restart

The engines ability to be started was tested at each of the performance measurement points following the manufacturer's recommended starting procedure. They were tested at an "ambient" state after the engines remained at lab temperatures (70°F) for 12 hours without running. They were also tested for hot restart/vapor lock. To test for hot restart/ vapor lock the engines were brought up to full operating temperature for a period of time, then they were turned off and placed in an insulated box to allow them to heat soak for 5-minute and then they were started. All of the engines passed the validation requirement of starting with in five pulls, regardless of fuel blend. Also, none of the engines exhibited any unusual starting during the aging process.

Load Pick-up and RPM Stabilization

A modified version of SAE standard J1444, *Procedure for evaluating transient response of small engine driven generator sets*, was used to measure the engines ability to pick-up load and the governor's ability to maintain a specific RPM. The testing was conducted while the engines were couple to the generator heads using a load bank. The frequency (directly proportional to RPM) of the electricity generated was monitored as the loads were applied. All of the engines regardless of fuel exhibited a frequency drop that was greater than the amount allowed of 4 Hz. The largest drop occurred at the beginning of the study when the E20 engines were switched from E0 baseline to the E20 initial blend. These engines experienced a 40% greater drop with E20 than they did on E0. By the end-of-life testing, the engines all acted similarly regardless of fuel.

Horsepower and Torque

The peak horsepower and torque were measured at the beginning of the emission tests on the dynamometer (Figure 6). To examine the horsepower and torque trends the outputs for the three engines running on each fuel were averaged, with the exception of E10 which was the average of two engines due to a mechanical issue greatly reducing the output of one of the engines. During the baseline testing when all engines were running on E0 the power output followed the rich to lean trend with the richest running engines producing the most power, 3.0HP and the leanest engines producing 2.7HP. Once the fuel was switched to the blends and the power was measured during the initial blend tests, the power changed very little, less than 5% between E0 baseline and the blends. By midlife testing, all engines produced an average power between 2.6HP and 2.7HP regardless of fuel. By end-of-life, the engine running on E15 produced the most power at 2.8HP and the rest of the engines produced 2.6HP. Only the E10 engines increased in power at end-of-life when the fuel was switched back to E0. The other engines produced the same power at end-of-life blend tests as they did at end-of-life E0. The engine torque followed the horsepower trends.

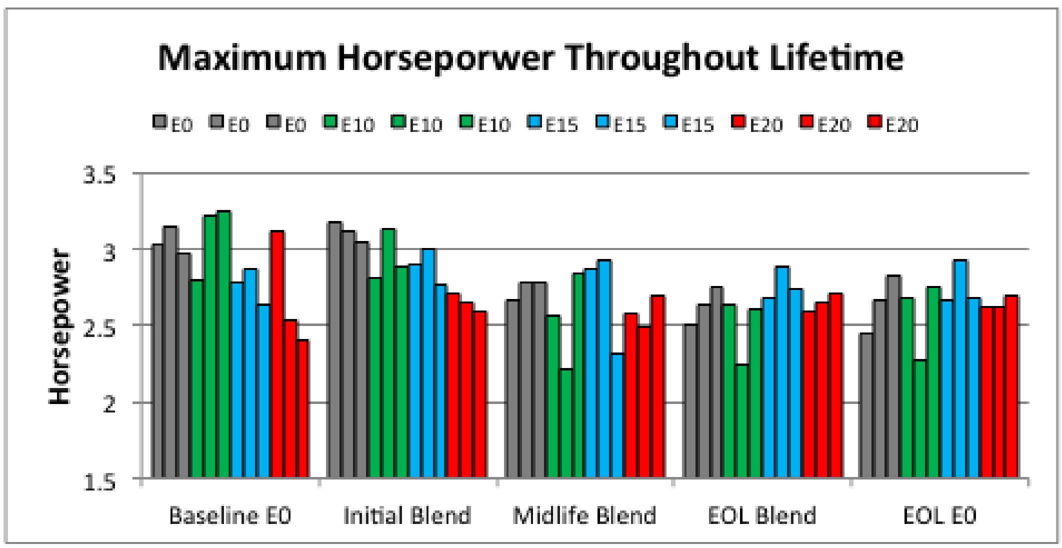

Figure 6 Horsepower for each engine at each performance measurement point

Temperatures

The crankcase oil, exhaust gas, cylinder head, and intake air temperatures were measured throughout the study. Peak temperatures were recorded during the mode 1 (100% load) of the emissions test on the dynamometer. The exhaust gas temperature (EGT) on average, increased for the E15 engines when they were switched from the baseline to the initial blend by 5%. At midlife, the E15 EGTs were similar to the other engines. No other EGT trends were observed between the fuels from start to finish.

Cylinder head temperatures generally increased with ethanol content, although the E20 engines exhibited lower temperatures than the E15 engines (Figure 7). The cylinder head temperature, on average, increased for the E15 engines when they were switched from the baseline to the initial blend by 5%. All engines experienced a decrease in cylinder head temperature from the baseline or initial blend tests to the end-of-life tests.

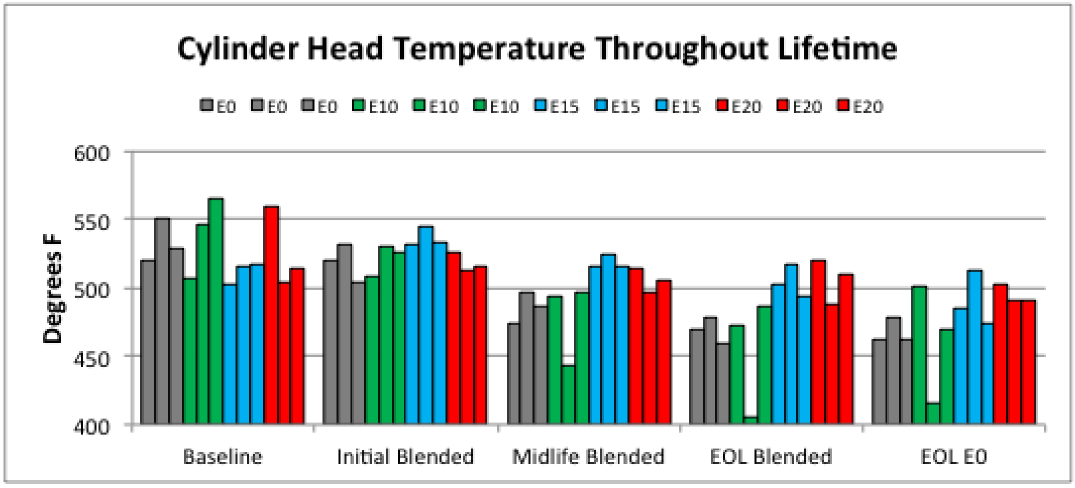

Figure 7 Cylinder head temperatures for each engine at each performance measurement point

The oil temperatures, on average, increased for the E15 engines when they were switched from the baseline to the initial blend by 4%. The engines running on E15 consistently had higher oil temperatures than the other engines. All engines experienced a decrease in oil temperature from the baseline or initial blend tests to the end-of-life tests.

Emissions

The emissions were measured following the code of federal regulations (CFR) part 90 6-mode rated speed test. The emissions were measured with a constant volume sampling (CVS) system and an eddy current dynamometer. Figure 8 shows the average change in emissions from baseline to end-of-life blend tests. The carbon monoxide (CO) emission decreased as the ethanol level increased from the baseline tests through the end-of-life tests. The oxides of nitrogen (NOx) emissions increased with the ethanol blends from the baseline tests through the end-of-life tests. Finally, the hydrocarbon emissions (HC) were highest with E10 and decreased with E15 and E20 compared to E0 throughout the testing.

Average Change In Emissions Over Lifetime

	HC	Nox	CO	CO2
E0 Change	17%	-4%	-1%	1%
E10 Change	19%	4%	-8%	8%
E15 Change	-26%	57%	-33%	8%
E20 Change	5%	37%	-35%	8%

Figure 8 Change in emission from E0 baseline tests to end-of-life blend tests

Disassembly Measurement and Inspection

Dimensional measurements of engine components were carried out after all other testing had been completed. When out of tolerance measurements were counted, E0 and E10 had a greater amount, 13 and 19 respectively, when compared to E15 and E20 which had 11 each. Almost all of the engines had valve tappet and valve seat wear regardless of fuel used. The E0 and E10 engines also had piston pin and connecting rod wear.

Visual inspection of the units also occurred during the tear down procedure. The visual inspection of the cylinder heads and piston crowns showed no apparent trends in discoloration, deposit type, or amount. The carburetors, regardless of fuel showed no signs of corrosion or deposits.