Small Engine Dynamometer and E85 Conversion

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ABSTRACT

With fuel costs on the rise many individuals are looking for ways to use cost effective alternative fuels while remaining environmentally friendly. Currently there are few low cost methods for testing the effects of alternative fuels in small utility engines. The goal of this research project was to design an apparatus that facilitates testing of these alternative fuels to determine the effects on engine components or performance. The efficiency and performance of the Kawasaki FH580V was measured and subsequent research and development done to improve the overall efficiency and performance while running ethanol based fuels.

INTRODUCTION

This design project was done at Minnesota State University Mankato in conjunction with The Toro Company. The intention of this project was to further explore the use of ethanol in small utility engines. It was necessary to run the engine in an environment that is close to its natural operating conditions to get accurate results. In order to replicate the engines working environment, a dynamometer test stand was constructed. This allowed accurate measurement of horsepower, torque, and the overall engine operation under load. A water brake dynamometer added load to the engine, and a strain gauge was used to measure its power output. For emissions testing, SAE J-1088 standard was consulted and a test procedure was developed. Engine sensors were installed to read critical engine parameters, and recorded by National Instruments LabView in a excel spreadsheet. Along with engine testing, materials compatibility tests were conducted to ensure that all components of the engine would withstand the ethanol based fuels. The compatibility testing was done on components found on the engines that came in contact with fuel or fuel vapor.

PROJECT OVERVIEW

Dynamometer

Extensive research was done to insure the proper dynamometer was chosen for this application. Criteria including cost, durability, packaging, maintenance, and adjustability were entered into a decision matrix (Appendix A). Through this matrix it was decided a water brake would best fit the application (Picture 1). The water brake has a controlled water inlet that allows water to enter into the center of the impeller rotation of the engine induces centrifugal to expel the water to the outside and into the stator. As the water comes in contact with the stator, it is decelerated and applies a load to the engine. Attachment of a load cell allows measurement of the torque on the dynamometer.

(Picture 1)

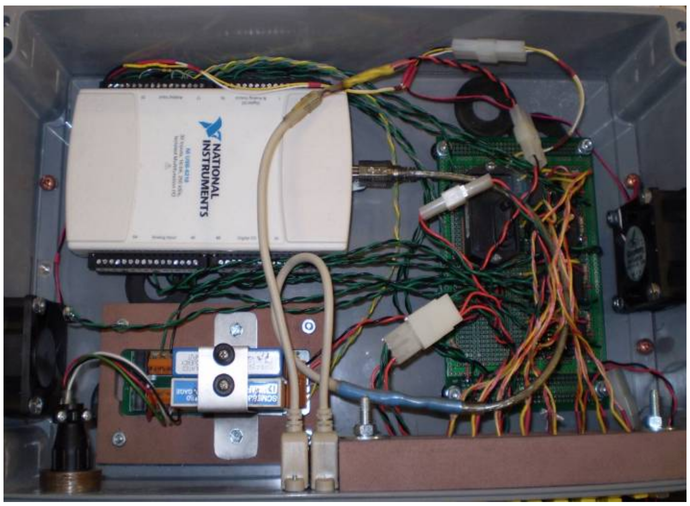
Coupler

The factors that were considered when choosing a coupler were durability, dampening, and low maintenance. The decision was made that a Lovejoy coupler would best fit the application based on engine power and RPM. A spider made of nitrile butadiene rubber is used in between the couplers for its dampening capacity as well as chemical resistance.

(Picture 2)

Data Acquisition Software

High speed data logging of engine operation was done using National Instrument's LabView. The software package was developed to suit the needs of this application and allows the viewing of real time data. The instrumentation monitored engine load, RPM, temperatures, as well as atmospheric conditions such as barometric pressure and relative humidity. From the data gathered, a horsepower correction factor based on SAE 1349 standard was developed as well as a barometric correction using SAE J1667. The sensor inputs used by LabView consisted of numerous voltages and one frequency. The circuitry on the board conditioned signals from the sensors into usable voltage inputs read by LabView via the NIUSB-6218 module.



(Picture 3)

Cart Construction

The design constraints of the cart were to house the water brake, engine, and storage while still remaining portable. The cart's design incorporates an adjustable engine mounting plate that will allow the engine to be moved up or down for varying engine shaft lengths. The top plate is also predrilled to fit an assortment of engine bolt patterns. A model of the cart was developed in Pro Engineer and for visual reference prior to construction (Appendix B). Complete picture of cart (Picture 4)

(Picture 4)

Engine Modification

The engine modifications were performed on a Kawasaki 19 HP FH580V (Appendix C). The basis of the research required that these engines be converted run on E-85. The conversion included two tiers: make the engine run with the least amount of modifications, and secondly to modify the engine for optimal performance.

Minimal Modification Engine

The stock carburetor jets were replaced with new jets that flow approximately 30% more fuel to achieve the proper air fuel ratio. During testing the main jet that was 30% larger had problems sustaining midrange load and the engine surged drastically in RPM. As a result the main jet size was increased to 60% larger than stock. The pilot or idle circuit was modified to increase fuel delivery at idle speeds. This modification involved resetting the pilot needle ½ turn passed the factory maximum setting. This is the final configuration used for emission testing.

Optimized Engine for E-85

To further optimize the engine for E-85 use it was necessary to increase the static compression ratio of the engine. The factory compression ratio was calculated at 8.25:1. Then the stock head was modified to reduce combustion chamber volume by filling with weld and resurfaced. Along with raising compression, modifications to the intake and exhaust ports were made to achieve higher air flow. The goals of these modifications were to increase power output while still maintaining reliability. The modifications are discussed in the following sections.

Stock Head

The stock cylinder head was first removed from the engine and completely disassembled. The heads were then measured and the data was entered into Port Flow Analyzer (Table 1). Using a SuperFlow model 60 the cylinder heads were flow tested to evaluate initial air flow. Areas in the ports where improvements could be made were identified and marked for porting.

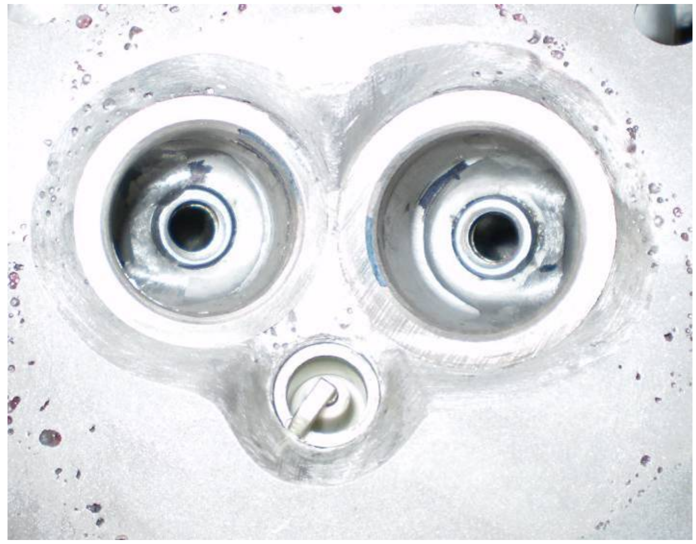
The stock cylinder head was flowed prior to any modifications; it flowed 31.26 uncorrected CFM at its peak flow point.

<u>Cylinder Head Specs.</u>	**Intake**	**Exhaust**
Valve Diameter	1.05”	0.951”
Stem Diameter	0.235”	0.233”
Throat Diameter	0.94”	0.845”
Average Seat Angle	45°	45°
Port Shape	Round	Round
Port Volume	15.4cc	21.8cc
Port Length	1.868”	2.634”
Max Lift Tested	.300”	.300”

(Table 1)

Combustion Chamber Modification
The stock combustion chamber is a hemispherical design with a 23.8cc volume (Picture 5). The volume of the combustion chamber was decreased in order to increase compression ratio and quench ratio. The final chamber design was determined by using clay molding inside the combustion chamber to visualize the results of welding the cylinder head. After the chamber design was finalized the cylinder head was prepared for welding. The seats and guides were removed, the head was wire brushed and sanded, washed, then heated to 400F. After the head has reached 400F it was welded in multiple passes. Next the head was post heated until the head stabilized at 400F. The cylinder head was then cooled slowly to prevent weld cracks. The final measured volume was reduced to 15.4cc. The original compression ratio was 8.25:1 and by decreasing the combustion chamber the compression ratio was brought up to 10.15:1. The final combustion chamber is shown in (Picture 6).

(Picture 5)



(Picture 6)

Intake Port Modification
The stock intake port was very restrictive, with many signs of factory machining and casting. The sharp edges and drastic angles were identified as the first thing to improve. The short turn radius angle was decreased thereby increasing the cross sectional area and straightening the port. The material around the valve guide was removed to streamline airflow. Air flow and velocity were greatly improved at high valve lift.

Valve and Seat modification
The valve and valve seat were identified as areas with high potential for improvement. A 2 angle valve job was performed on the seat using a 46° seat cut, a 60° throat cut. A 30° cut was made on the back of the valve’s head, both steps showed great improvement at low lift flow.

Complete modification
With all porting, valve work and combustion chamber modifications completed, the cylinder head was reflowed. This final flow test confirmed the previous test results demonstrated that combustion chamber design can improve port flow. With all modifications complete the head had 44.03 uncorrected CFM, an increase of approximately 40% at peak flow over stock configuration (Appendix D). Table 2 shows the difference in port volume from the stock cylinder head to the modified head. The intake port was enlarged in the short turn radius to facilitate higher flow. The exhaust port was smoothed but lost volume due to the valve job.

Port	Intake	Exhaust
Stock	15.4 cc	21.8 cc
Modified	16.8 cc	21.6 cc

(Table 2)

Port Mold
A mold of the intake port was made to allow easy examination of the port shape. This mold can be used to accurately measure cross sectional areas throughout the port's length, as well as visually identify other possible areas for further improvement. This was the final step in the modification process. Here is a picture of the port mold (Picture 7)

(Picture 7)

MATERIAL COMPATIBILITY
In addition to evaluating the performance of this engine on E85, the study also included an evaluation of E20. This component was intended to add data to the E20 material compatibility study recently completed at Minnesota State University, Mankato that tested raw metals, plastics and elastomers exposed to different blends of ASTM Fuel C; 90% Fuel C and 10% aggressive ethanol; and 80% Fuel C with 20% aggressive ethanol.

Based on the results from the initial research project, the following materials were approved because of non failures in the study. The main casting of the carburetor is A380 standard die cast aluminum. The rubber O-rings are of a NBR elastomeric composition, and Viton is used for the inlet needle tip. The float is made of Nylon.

The fuels that were used in the tests are from the SAE standard J1681, Gasoline, alcohol and diesel fuel surrogates for materials testing. The three fuels used are blended as follows:

E10 fuel $[C(E10)_A]$- 90% Fuel C + 10% aggressive ethanol (450ml toluene, 450ml iso-octane, 100ml aggressive ethanol)

E20 fuel $[C(E20)_A]$- 80% Fuel C + 20% aggressive ethanol (400ml toluene, 400ml iso-octane, 200ml aggressive ethanol)

E85 fuel $[C(E85)_A]$- 15% Fuel C + 85% aggressive ethanol (75ml toluene, 75ml iso-octane, 850ml aggressive ethanol)

Aggressive ethanol consists of: synthetic ethanol 816.00gm, de-ionized water 8.103gm, sodium chloride .004gm, sulfuric acid .021gm, glacial acetic acid .061gm (SAE J1681).

ASTM Fuel C was used as a gasoline surrogate due to its worst case scenario composition for damage to materials. Its composition is 50% iso-octane and 50% toluene.

Three separate component tests were conducted to test ethanol fuel compatibility. The first used the fuel float bowl system to keep the controlled level of fuel in the fuel bowl. This simulates the engine when it's not being used. The second set of tests was the carburetor fully submerged in fuel to test all of the materials exposed as it is when the engine is in operation. The third test consisted of a complete soak of the fuel pump to make sure the diaphragm isn't affected by the ethanol.

Test Procedures
The float level testing looked at three components: material weight, physical change such as swelling, cracking, or corrosion, and fuel jelling in the float bowl. Before soaking, the weight of the fuel bowl, float, jet, needle, and stripped down carburetor were recorded. The float height and cork gasket thickness were also recorded.

Three carburetors were used, one for each fuel, and were placed in an oven at 55 ºC to accelerate the corrosion. A fuel reservoir was placed above the carburetor to provide the inlet with fuel to keep the fuel level up. Plates were also fabricated to close off the carburetor to slow evaporation. At the end of the soak the measurements were compared to the initial values to determine if a significant change occurred.

(Picture 8) Float Bowl specimens set up, ready for soaking.

The complete soak was also one carburetor for each fuel. The carburetors were placed fully submerged in a container of fuel. This portion of the test was simply looking for corrosion cause by reactions between the different metals and the ethanol. All of the same measurements were also taken on this set of carburetors and recorded. The results were looking for the changes of effects as the level of ethanol increased.

The fuel pump soak was also placed in a container of fuel fully submerge the fuel pump. One fuel pump was kept away from fuel as a reference. After the soak, the pumps were taken apart and examined for damage to the diaphragm that would cause the pump to fail. Again the results were compared to each because E10 is already accepted for use.

(Picture 9) All samples in the oven to begin soak.

Results

In order for the carburetor and fuel pump to be considered compatible with E20 and E85, it must not undergo significantly different changes than it did with E10. Also the float height and swelling must not changed to a point where it would cause the carburetor or fuel pump to fail.

Weight change

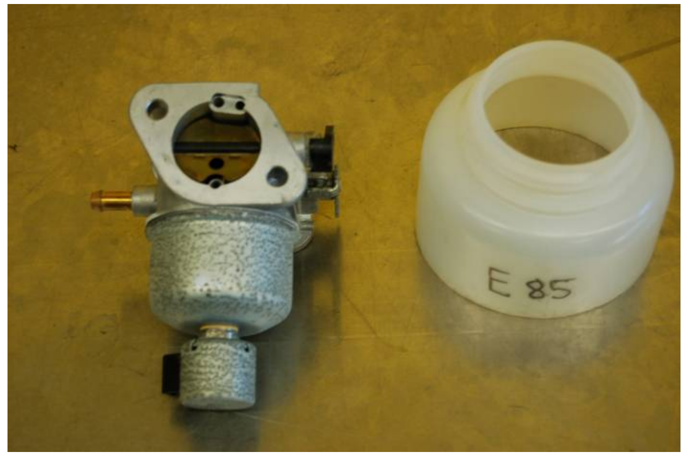
After soaking both completely submerged and at normal float level, no significant weight changes were found across the fuels. The float weight increased in both studies, but increased close to the same with each fuel.

Float Height change

The float height was the biggest measured change. In the float bowl samples, E85 dramatically changed the height of the float. Yet in the completely submerged samples, float height change decreased with more ethanol. These two contrasting results show the need for further study, with more samples to provide consistency.

Visual change

Visual change results are the most concerning from these tests, the picture below shows the E85 carburetor from the complete soak set. There is a large amount of corrosion on the float bowl, the fuel shutoff switch and the throttle lever. The same amount of corrosion was found on the inside of the E85 float bowl sample. Little or no corrosion was found on the E10 and E20 samples, suggesting that the plating used on these parts of the carburetors have compatibility issues, and different plating should be used.



(Picture 10) Corrosion on the submerged E85 carburetor

Cork Gasket

The cork gasket showed no significant changes between fuels, and the measurements only varied by .001”.

Fuel Pump Results

After the fuel pumps were dried out in the oven, they were examined to check for sealing and free moving diaphragms by seeing if air could go in and out each port, and compared it against a new one. The pumps were also taken apart to check for hardness of the diaphragm. No significant changes were found between any of the three fuels, or between a new pump.

Summation

With the recording weights of the float, float bowl, the jet, the needle and the rest of the carburetor, no significant changes were found. The varying amount between the float heights should be further tested with a larger sample size but does not conclude the carburetor to be not compatible with E20 or E85. The visual change however with the corrosion of the plating on the float bowl, fuel shutoff and the throttle lever should be noted and different plating should be used in E85 applications. For more detail of fuel compatibility testing procedure (Appendix E) and the data collected refer to (Appendix F).

Emission Testing

Testing was done to compare a stock engine to all fuel and engine modification in regards to all emission outputs. The emission standard being used is SAE J-1088, (The Measurement of Gaseous Exhaust Emissions from Small Utility Engines). Emission testing was used in conjunction with LabView software to log information. The testing was conducted under steady state operating conditions at the 6 different modes prescribed by J-1088. The cycles range from 100% load to idle. Data was recorded for each test cycle run for 2 minutes after engine operating conditions stabilized. Emission testing was performed on a stock engine to obtain baseline data and then after each engine modification to determine any incremental changes in performance.

The fuels used in testing were Tier II, E-10, E-20, and E-85. All fuels were blended using Tier II and fuel grade ethanol to ensure correct mixtures and consistent fuel properties. A test procedure was written for repeatability. (Appendix G)

Baseline testing: Tier II

The test was done after the cylinder head temps had stabilized within 10 degrees of a pre-established temperature between each mode. The testing results for Tier II are in Table 3.

Tier II

Test Results

Load Percent	HP	RPM	Torque	BSFC
100%	17.5	3090	28.24	0.60
75%	14.4	3362	21.46	0.53
50%	10.0	3491	14.37	0.60
25%	4.1	3569	5.79	1.05
10%	1.9	3589	2.73	1.72
Idle	0.5	1812	1.25	2.99

Table 3

E-10

The test was done after the cylinder head temps had stabilized within 10 degrees of a pre-established temperature between each mode. The testing results for E-10 are in Table 4.

E-10

Test Results

Load Percent	HP	RPM	Torque	BSFC
100%	17.6	3087	28.32	0.57
75%	14.5	3357	21.30	0.52
50%	10.2	3476	14.57	0.58
25%	5.2	3539	7.32	0.81
10%	2.0	3573	2.85	1.68
Idle	0.3	1773	0.95	4.33

Table 4

E-20

The test was done after the cylinder head temps had stabilized within 10 degrees of a pre-established temperature between each mode. The testing results for E-20 are in Table 5.

E-20

Test Results

Load Percent	HP	RPM	Torque	BSFC
100%	17.8	3101	28.59	0.58
75%	14.5	3363	21.37	0.55
50%	10.0	3479	14.32	0.59
25%	5.2	3531	7.31	0.87
10%	1.9	3566	2.80	1.73
Idle	0.2	1765	0.68	6.10

Table 5

Carburetor modification-E-85

In order for the engine to run on E-85 it was necessary to enlarge the main jet on the carburetor to allow roughly 30% more fuel flow. The test was done after the cylinder head temps had stabilized within 10 degrees of a pre-established temperature between each mode. The testing results for E-85 are in Table 5.

E-85 CARB

Test Results

Load Percent	HP	RPM	Torque	BSFC
100%	18.3	3118	30.57	0.71
75%	15.6	3411	22.92	0.69
50%	10.9	3521	15.59	0.71
25%	5.3	3578	7.48	0.98
10%	2.2	3612	3.10	1.86
Idle	0.2	1619	0.72	8.46

Table 5

Cylinder Head modification-E-85

The stock cylinder heads were replaced with the modified once describes previously. The test was done after the cylinder head temps had stabilized within 10 degrees of a pre-established temperature between each mode. The testing results for the E-85 modify cylinder head are in Table 6.

E-85 Mod Head

Test Results

Load Percent	HP	RPM	Torque	BSFC
100%	17.9	3110	30.74	0.71
75%	14.9	3336	22.98	0.66
50%	10.4	3435	15.48	0.70
25%	5.3	3481	7.72	0.94
10%	2.1	3508	3.06	1.87
Idle	0.3	2219	0.59	8.74

Table 6

Emission Weighting Factor

The data collected was weighted by each mode according to the Environmental Protection Agency. The standard that was followed was ISO 8178, which is an international standard designed for non-road engine applications. The test cycles used within this standard was the B-type. The factors are shown in Table 7.

Utility, lawn and garden (Weighting Factors)						
Mode	1	2	3	4	5	6
Torque%	100%	75%	50%	25%	10%	Idle
Type G1	0.09	0.20	0.29	0.30	0.07	0.05

Table 7

Emission Data

The emissions measurements obtained during each test were averaged and multiplied by the weighted factors. The emission comparison (G/Bhp-hr) for Mode 1 though Mode 6 were added together to show the overall emission. The overall hydrocarbon emission (HC) is shown in (Chart 1), overall carbon monoxide (CO) is shown in (Chart 2), and the overall oxide of nitrogen (NOX) is shown in (Chart 3). The full correlation of emission between the fuels and specific mode can be seen in (Appendix H). The comparison of emission between the different fuel mixtures and modes is in (Appendix I).

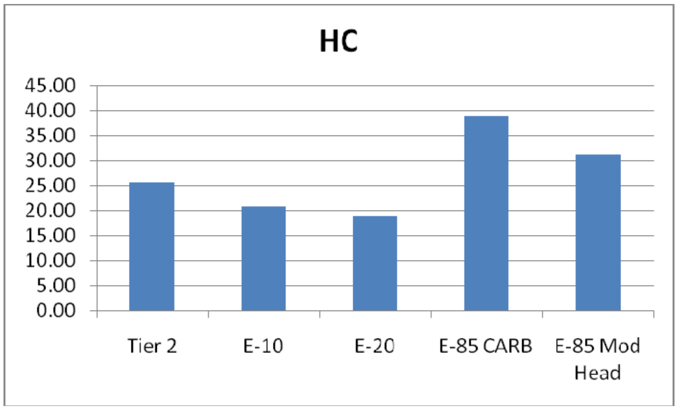


Chart 1 (G/Bhp-hr)

Chart 1 illustrates the trend of hydrocarbons between the different fuels tested. The spike in the E-85 is asumued to the lack of ajustment in the carburator. (excessivly rich in mode 5 and 6 of E-85 testing)

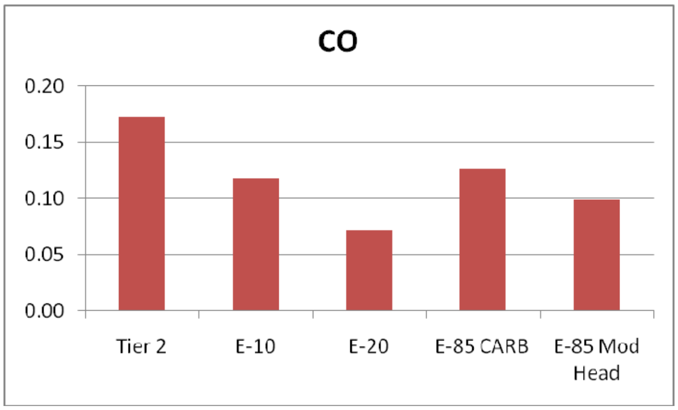


Chart 2 (G/Bhp-hr)

Chart 2 illustrates the trend of carbon monoxide between the different fuels tested. The CO decreases with the increase of ethanol. The spike in the E-85 is asumued to the lack of ajustment in the carburator. (excessivly rich in mode 5 and 6 of E-85 testing)

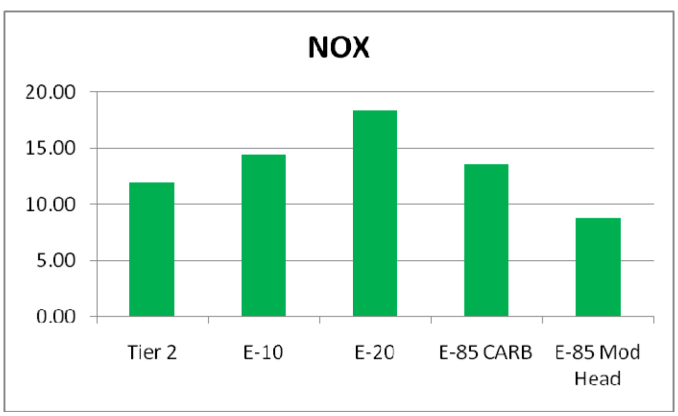


Chart 3 (G/Bhp-hr)

Chart 3 illustrates the trend of oxides of nitrogen between the different fuels tested. The Nox increases with the increase of ethanol. The lower reading for E-85 was in part because the engine was running cooler and therefor not fully otimized for the use of E-85.

Emission Exhaust Gas Temperature Correlation

During the duration of the emission testing the exhaust gas temperature was average to show the change in variation of the fuel. The exhaust gas temperature averaged was multiplied by the weighted factors and all modes were added together to show and accurate trend shown in (Chart 4). The comparison for all exhaust gas temps is shown for each mode in (Appendix J).

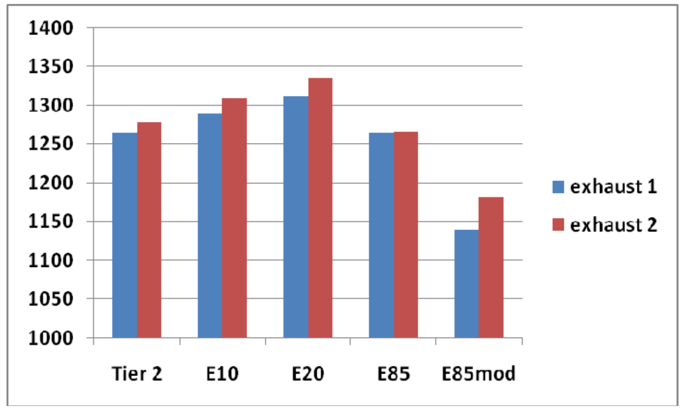


Chart 4 (Exhaust Gas Temperatures)

Emission Cylinder Head Temperature Correlation

During the duration of the emission testing the exhaust gas temperature was average to show the change in variation of the fuel. The cylinder head temperature averaged was multiplied by the weighted factors and all modes were added together to show and accurate trend shown in (Chart 5). The comparison for all cylinder head temps is shown for each mode in (Appendix K).

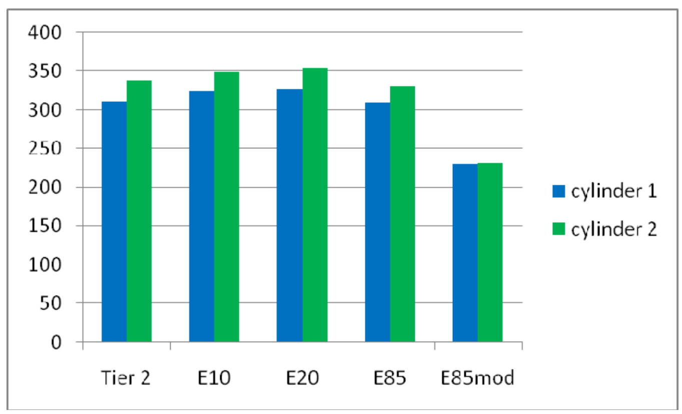


Chart 5 (Cylinder Head Temperatures)

Cost of Operation

By using the calculated BSFC and the horsepower generated at maximum torque the cost of operation per hour was calculated for Tier 2, E-10, E-20, and both E-85 test modes. Tier II was included and the price that was used was from a non-oxygenated pump. The average fuel costs state wide (5/30/08) for regular unleaded and E-85 were used to calculate operating cost. The price of the fuels is shown in (Table8). The average for E-10 was also used for E-20. The brake specific fuel consumption of the fuels used was multiplied by the weighted factors and all modes were added together shown in (Chart 6). The operational cost is shown in (Chart 7).

Tier 2	E-10	E-20	E-85
$4.05	$3.69	$3.69	$3.04

Table 8

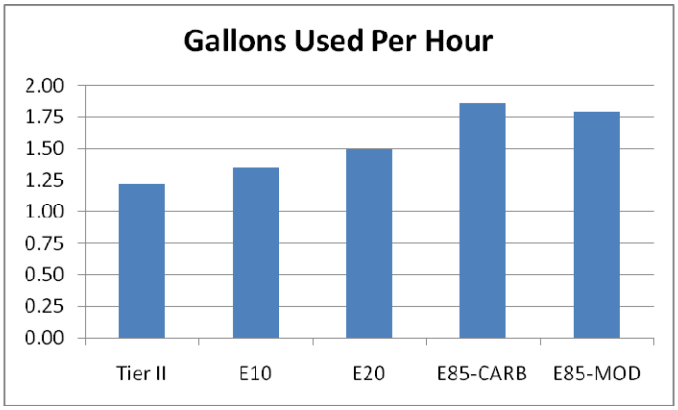


Chart 6 (Gallons used)

Chart 7 (Cost of Operation)

CONCLUSION

Results of this research indicate E-85 is a viable alternative fuel source for small utility engines. The resources are available to convert existing engines to run on E-85 with minimal cost and modifications. Emissions testing showed a trend for improved emissions when using higher percentage concentrations of ethanol, although further tuning and testing is required for conclusive results. With additional engine development and a correct tune, E85 has the potential for being a cost effective and environmentally friendly alternative fuel for small utility engines.

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APPENDIX

A.) Dynamometer Design matrix

B.) Dyno Cart Drawings

C.) Stock Kawasaki engine Specs.

D.) Cylinder Head Flow Graph

E.) Fuel Compatibility Test Procedure

F.) Fuel Compatibility Data tables/charts

G.) Emission test procedure

H.) Emission Data Tables

I.) Emission Graphs

J.) Emission Exhaust Temperatures

K.) Emission Cylinder Head Temperatures

Appendix A

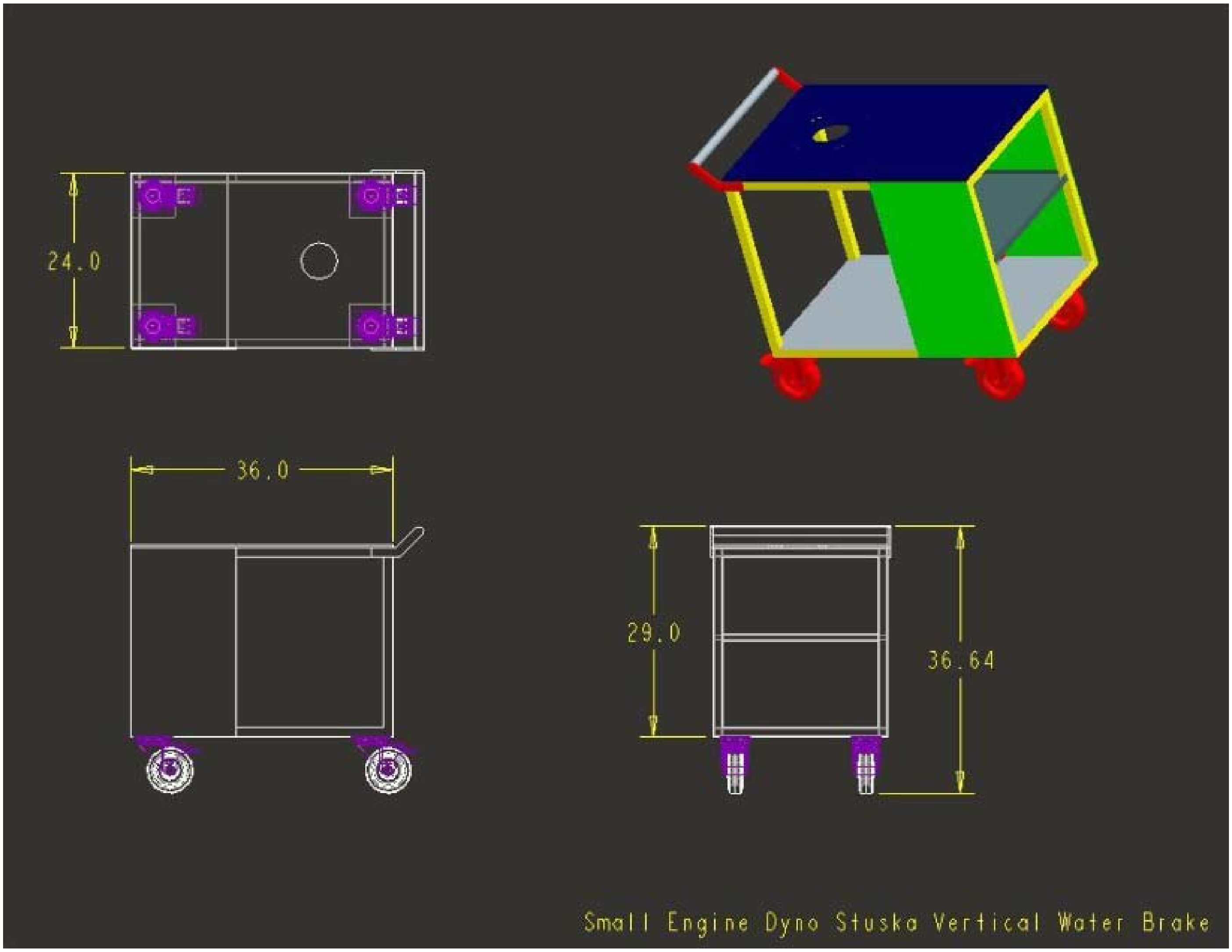
Type of Dynamometer

Decision Matrix

Item	Cost	Weighted value	Packaging	Weighted value	Durability	Weighted value	Maitenace	Weighted value	Supervision	Weighted value	Load Ajustabilty	Weighted value	TOTAL SCORE
Eddie Current	1	0.1	5	0.75	1	0.25	9	1.8	5	0.5	9	1.8	5.2
Inertia	9	0.9	1	0.15	9	2.25	9	1.8	9	0.9	1	0.2	6.2
Water Brake	9	0.9	9	1.35	5	1.25	5	1	5	0.5	9	1.8	6.8
Hydraulic	5	0.5	9	1.35	5	1.25	5	1	5	0.5	9	1.8	6.4

values	
	1 poor
	5 fair
	9 good

Appendix B

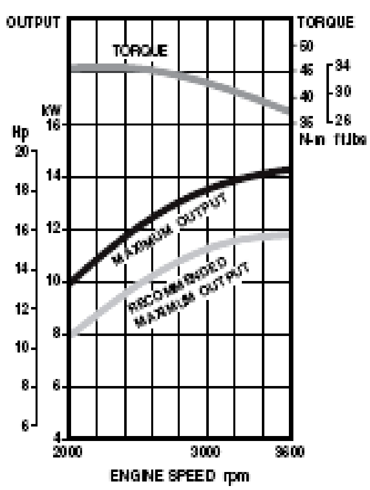

24.0
36.0
29.0
36.64
Small Engine Dyno Stuska Vertical Water Brake

Kawasaki
FH580V

585CC, 19HP / 3600RPM

- Overhead V-Valve
- 90° V-twin
- Pressurized Lubrication
- Electronic Spark Ignition
- Automatic Compressor Release
- Dual Element Air Cleaner
- Inner Vent Carburetor
- Rotating Grass Screen
- Cast Iron Cylinder Liners

Performance Curves



Engine Data

Engine Type	Forced Air Cooled V-twin 4-cycle Vertical Shaft OHV Gasoline Engine
Number of Cylinders	2
Bore x Stroke	2.91x2.68 in. (74x68 mm)
Displacement	585 cc (35.7 cu. in.)
Compression Ratio	8.5:1
Maximum Power	19.0 HP (14.2 kW) / 3600 rpm
Maximum Torque	27.9 ft. lbs. (37.8 N•m) / 2400 rpm
Oil Capacity	1.9 U.S. qt. (1.8 liter) w/Filter
Dry Weight (Without Muffler)	71.2 lbs. (32.3 kg)

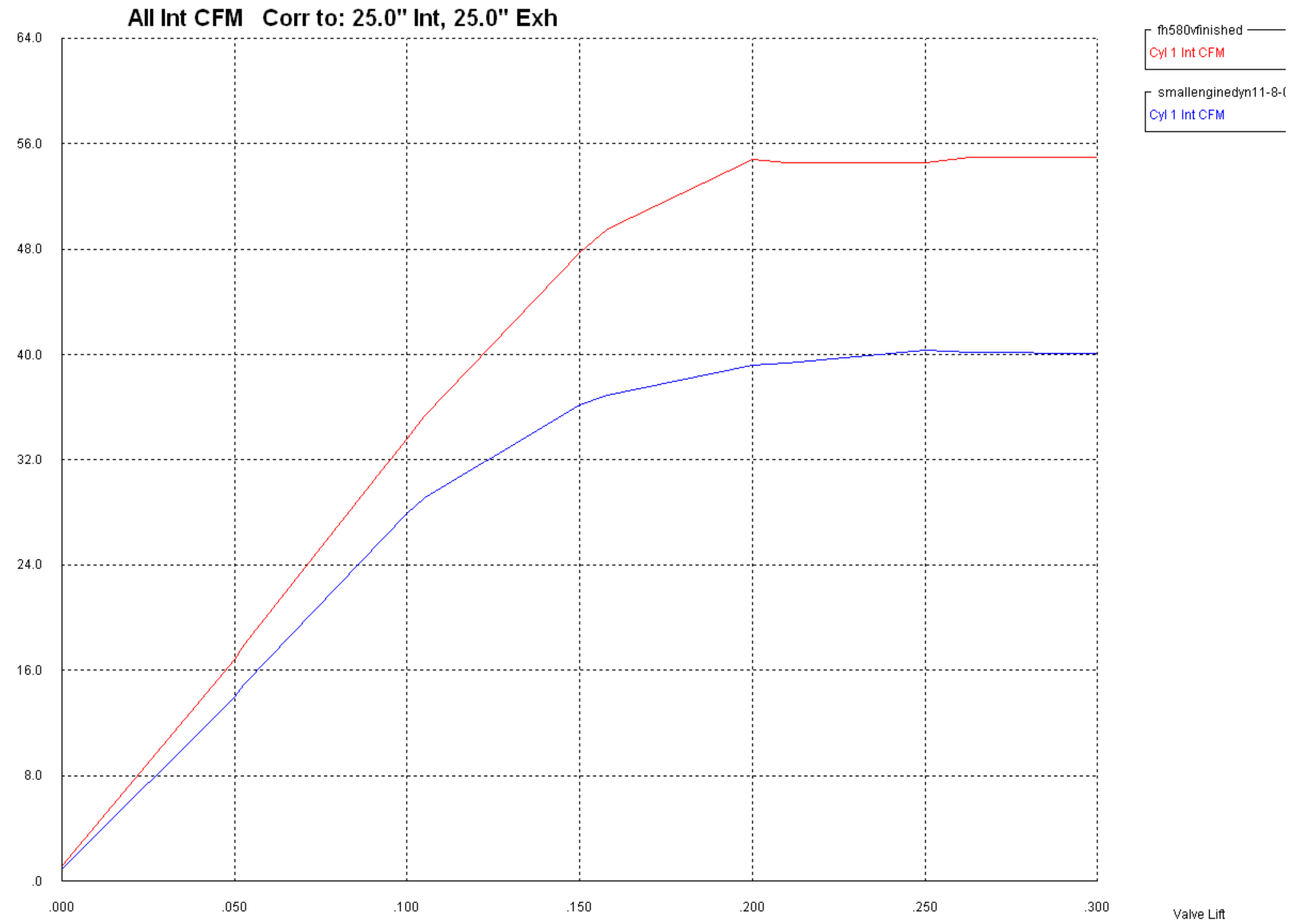
General Specifications

Engine Code	S01	S02	S03
Crank Shaft (PTO)	1" straight shaft with 1/4" straight keyway		
Starter	Electric-Bendix Type	Recoil	Recoil
Muffler	Side Mount	Side Mount	Side Mount
Charging Coil	15 Amp	See Note	None
Regulator/Rectifier	◆	◆	
Fuel Pump	Pulse Type	Pulse Type	Pulse Type
Oil Filter	◆	◆	◆
Rotating Screen Guard	◆	N/A	N/A
Control Panel	Associated Throttle/ Choke		
High Idle RPM	3600	3600	3600

Note: Charging coil includes built in rectifier and is designed for an electric clutch without a battery.

Appendix D

<u>Stock Intake Flow compared to All Intake Modifications</u>



(Top is All Intake Modifications)
(Bottom is Stock Intake Flow)

Appendix E

MnCAR

Minnesota Center for Automotive Research

4-9-08

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(507) 389-5002 (fax)

RE Small Engine Dyno

Material Compatibility Overview: Continuing a material compatibility test being done here, ethanol blended fuel will be soaked in Walbro LMF carburetor bowls for 1500 hours. The fuel used is planned to be test fuel C, E10, E20, and E85. The purpose of this testing is to determine if fuel $C(E20)_A$ will a larger negative impact with the carburetor system than fuel "C" or $C(E10)_A$, and what kind of negative impact $C(E85)_A$ will have on the carburetor as a whole unit. The following properties and changes will be examined before and after immersion: swelling, weight, float height and fuel jelling up in the float bowl. Three tests will be performed on the fuel system. The first is having the float bowl fed with an auxiliary tank to represent normal storage situations. The second will have a fully submerged carburetor and the third will be the fuel pump completely submerged in fuel and then cut apart for examination of the diaphragm and pump system to check for failure.

Standards Used: Proposed testing will follow the procedures outlined in:

SAE J1747 (Dec94):	Recommended Methods for Conducting Corrosion Tests in Gasoline/Methanol Fuel Mixtures
SAE J1748-98	Methods for determining physical properties of polymeric materials exposed to gasoline/oxygenate Fuel Mixtures
SAE J1681-00	Gasoline, alcohol, and diesel fuel surrogates for material testing

Test Fuels: Four test fuels will be used consisting of:

"C"	Surrogate gasoline- "base" ASTM fuel "C" 50/50 toluene iso-octane mixture (500ml toluene, and 500ml iso-octane)
"$C(E10)_A$"	E10 fuel- 90% fuel C + 10% aggressive ethanol (450ml toluene, 450ml iso-octane, 100ml aggressive ethanol)
"$C(E20)_A$"	E20 fuel- 80% fuel C + 20% aggressive ethanol (400ml toluene, 400ml iso-octane, 200ml aggressive ethanol)
"$C(E85)_A$"	E85 fuel- 15% fuel C + 85% aggressive ethanol (75ml toluene, 75ml iso-octane, 850 ml aggressive ethanol)

Aggressive ethanol consists of: synthetic ethanol 816.00gm, de-ionized water 8.103gm, sodium chloride .004gm, sulfuric acid .021gm, glacial acetic acid .061gm (SAE J1681 appendix E.1.2)

Properties Inspected:

- Weight of bowl

- Weight of float
- Jelling of fuel

Appendix E

- Swelling of o-ring
- Swelling of cork gasket

Swelling, shrinking and/or cracking of plastic

- Swelling of fuel hose

Pre-Immersion Procedure:

1. Take a picture of the bottom of each carburetor and the inside of the bowl next to each other.

2. Weigh and record the carburetor bowl, the plastic float, the cork gasket and the rubber o-ring separately on an analytical scale up to four decimal places.

3. Measure the thickness of the rubber o ring in four places around it. Also measure the thickness of the cork seal in four different places around it.

4. Measure the float height by holding the carburetor upside down and measuring from the aluminum casting where the rubber o-ring sits to the bottom of the float.

5. Measure leaking through needle with float up. Hold the carburetor upside down and try blowing through the inlet. The weight of the float alone should seal the needle tip.

6. Place the fuel tanks used for testing in the oven and allow them to reach 45 °C ± 2 °C. The fuel tanks will not be sealed tightly to avoid pressure build up.

7. Once warmed up the reassembled carburetors will be connected to the fuel cell with the hoses they use on the engine and placed upright in the oven so the float bowl will be filled as it is when it is on an engine.

Immersion Procedure:

- Inspect weekly for fuel leakage and fuel tank level. After 4 weeks the fuel will be changed.

- If there are any spills of fuel, the cause will have to be determined and fixed in order for the test to continue safely.

- Any drastic results noticed during inspections will be photographed.

- Continue exposure for 500 hours so equilibrium between the fuel and materials is reached.

- After 1500 hours are reached, remove the carburetors from the oven.

Post Immersion Procedure:

1. Cool the fuel and carburetors by leaving them in a fume hood for an hour.

2. Measure the thicknesses of the o-ring and cork seal the same as in the pre-measurements.

3. Measure leaking through needle with float up. The same procedure as used in pre-immersion will be used.

4. Pictures are to be taken in the same position as presoak pictures to document any corrosion, swelling, pitting or jelling in the fuel bowl.

5. Clean the float bowl with a bristle brush and a mild abrasive to remove any corrosion and jelling.

6. The carburetors will be left to dry for 16 hours to make sure there is no remaining water or fuel, then and the individual parts will be weighed again on the analytical scale.

Appendix F

APPENDIX F	Table 1							Page 1
Minnesota State University,Mankato								
E85 Carburetor Study					Float Bowl Carburetor Results			

Float Height	E10	E20	E85
Pre-Immersion	0.585	0.576	0.566
Post Immersion	0.616	0.600	0.641
% Change	5.4%	4.1%	13.3%

Float Weight	E10	E20	E85
Pre-Immersion	4.815	4.832	4.834
Post Immersion	4.913	4.966	4.980
% Change	2.0%	2.8%	3.0%

Carb Weight	E10	E20	E85
Pre-Immersion	196.939	198.151	197.718
Post Immersion	197.012	198.297	197.875
% Change	0.0%	0.1%	0.1%

Bowl Weight	E10	E20	E85
Pre-Immersion	35.940	37.282	35.788
Post Immersion	35.938	37.187	35.805
% Change	0.0%	-0.3%	0.0%

Jet Weight	E10	E20	E85
Pre-Immersion	2.182	2.182	2.184
Post Immersion	2.183	2.180	2.183
% Change	0.0%	-0.1%	0.0%

Needle Weight	E10	E20	E85
Pre-Immersion	0.520	0.512	0.518
Post Immersion	0.521	0.512	0.520
% Change	0.2%	0.1%	0.5%

Cork Thickness	E10	E20	E85
Pre-Immersion	0.028	0.028	0.027
Post Immersion	0.028	0.027	0.026
% Change	0.0%	-3.6%	-3.7%

Results (% Change)	E10	E20	E85
Float Height	5.36%	4.11%	13.25%
Float Weight	2.04%	2.77%	3.02%
Carb Weight	0.04%	0.07%	0.08%
Jet Weight	0.04%	-0.10%	-0.04%
Bowl Weight	-0.01%	-0.26%	0.05%
Needle Weight	0.19%	0.14%	0.46%
Cork Thickness	0.00%	-3.57%	-3.70%

Appendix F

APPENDIX F **Table 2** **Page 2**

Minnesota State University,Mankato

E85 Carburetor Study **Submerged Carburetor Results**

Float Height	E10	E20	E85
Pre-Immersion	0.566	0.582	0.575
Post Immersion	0.599	0.594	0.576
% Change	5.8%	2.1%	0.2%

Float Weight	E10	E20	E85
Pre-Immersion	4.829	4.817	4.815
Post Immersion	4.967	4.902	4.976
% Change	2.9%	1.8%	3.3%

Carb Weight	E10	E20	E85
Pre-Immersion	199.455	197.291	196.988
Post Immersion	197.187	197.276	196.966
% Change	-1.1%	0.0%	0.0%

Bowl Weight	E10	E20	E85
Pre-Immersion	36.057	34.945	36.169
Post Immersion	36.057	34.944	36.271
% Change	0.0%	0.0%	0.3%

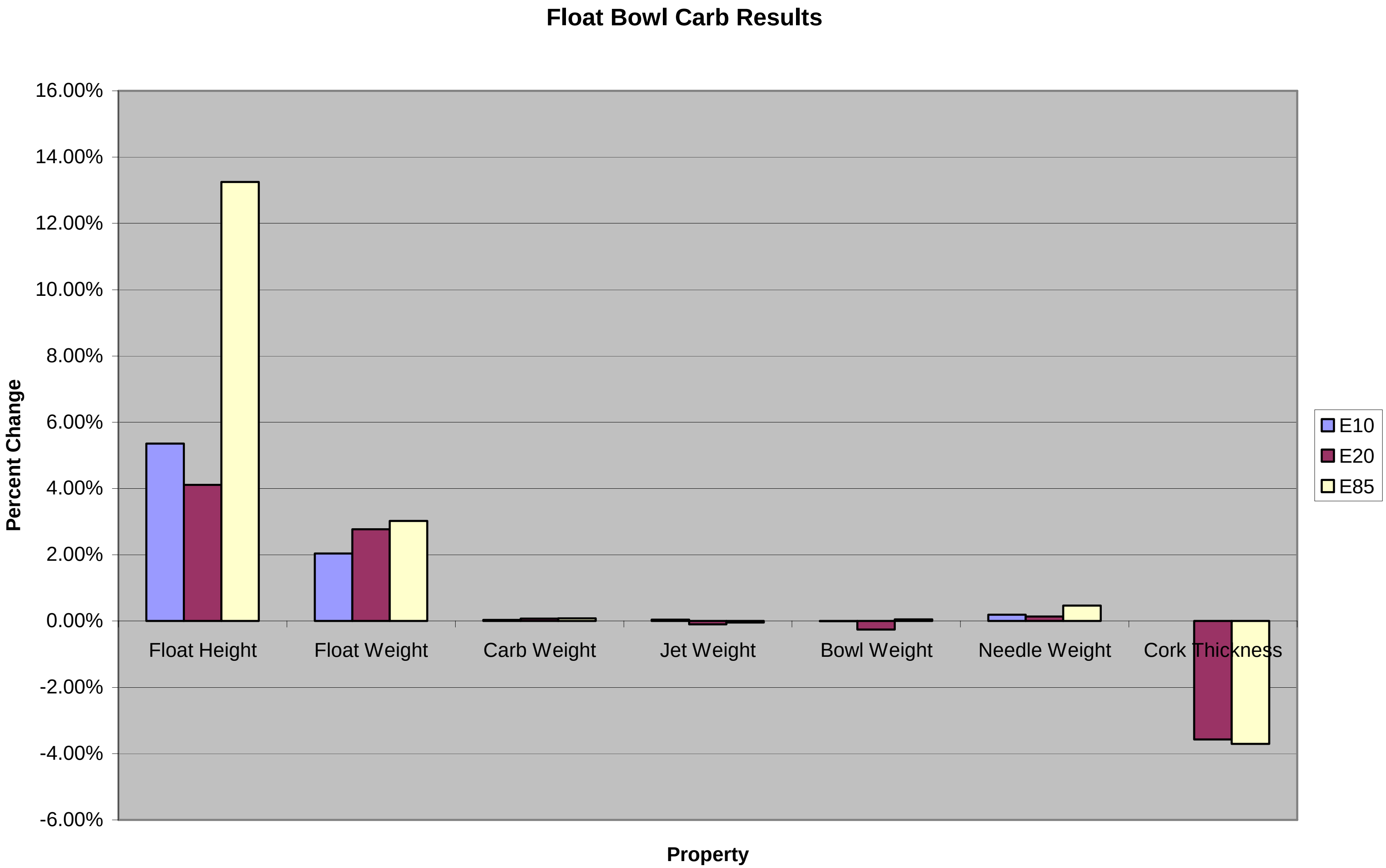
Jet Weight	E10	E20	E85
Pre-Immersion	2.183	2.183	2.183
Post Immersion	2.185	2.184	2.181
% Change	0.1%	0.0%	-0.1%

Needle Weight	E10	E20	E85
Pre-Immersion	0.522	0.520	0.520
Post Immersion	0.515	0.522	0.521
% Change	-1.3%	0.2%	0.2%

Cork Thickness	E10	E20	E85
Pre-Immersion	0.029	0.027	0.028
Post Immersion	0.028	0.028	0.027
% Change	-3.4%	3.7%	-3.6%

Results (% Change)	E10	E20	E85
Float Height	5.83%	2.06%	0.17%
Float Weight	2.86%	1.76%	3.35%
Carb Weight	-1.14%	-0.01%	-0.01%
Jet Weight	0.06%	0.02%	-0.07%
Bowl Weight	0.00%	0.00%	0.28%
Needle Weight	-1.34%	0.23%	0.17%
Cork Thickness	-3.45%	3.70%	-3.57%

APPENDIX F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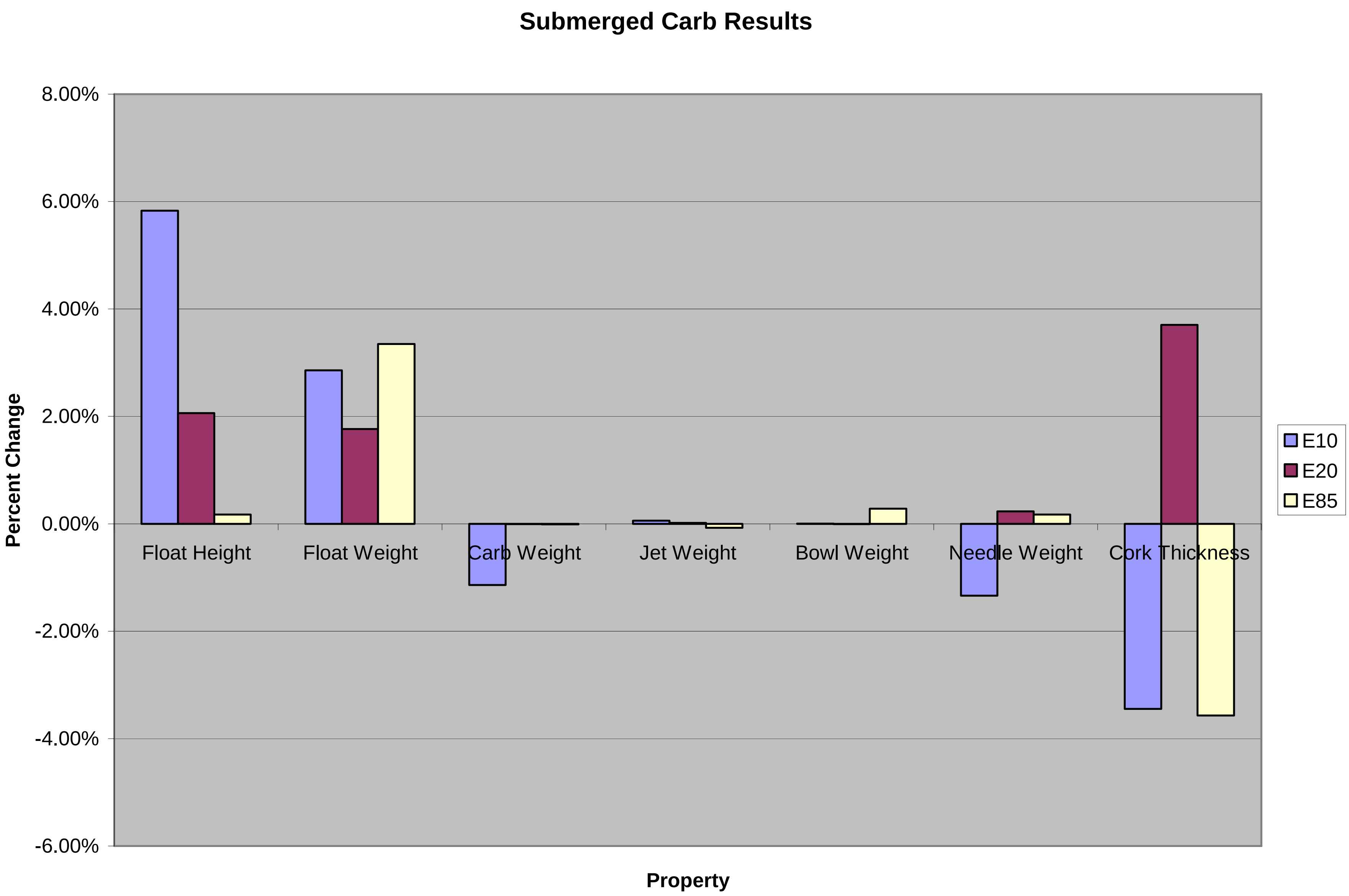
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
-6.00%
Percent Change
Float Height
Float Weight
Carb Weight
Jet Weight
Bowl Weight
Needle Weight
Cork Thickness
Property
E10
E20
E85


Submerged Carb Results
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6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
-6.00%
Percent Change
Float Height
Float Weight
Carb Weight
Jet Weight
Bowl Weight
Needle Weight
Cork Thickness
Property
E10
E20
E85

Appendix G

Small Engine Dyno Team
Emission Testing
SAE-J1088 standard

Engine test setup:

Required variables to be measured:

- Inlet air temp.
- Inlet air humidity
- Barometric pressure
- Fuel mass flow rate
- engine speed
- engine brake torque output

Fuel flow measurement:

- Use graduated cylinder to measure fuel volume usage
- combined accuracy of instruments to be within 2%

Air flow measurement:

- Laminar flow meter
- Pressure wave damping chamber 50 times greater than displacement of engine

Exhaust gas sampling system:

- Stock exhaust system supplied on engine
- Exhaust sampling probe
  - Straight closed stainless steel
  - Multi-hole probe
  - ID of probe must be less than or equal to ID of sample line
  - Wall thickness on probe shall be 1 mm or less
- Exhaust mixing chamber
  - Mount between muffler and sampling probe
  - Internal volume must be at least 10 times cylinder displacement
  - Suggested Temp. range from 175 to 400 C – (temp measurement required)

Set up for Emission Gas Analyzer

- Analytical methods and Calibrations
  - HC- flame ionize detector (FID)
  - Carbon Monoxide- Non dispersive infrared analyzer (NDIR)
  - Carbon Dioxide (NDIR)
  - Oxides of Nitrogen (NOX)- Chemiluminescent analyzer (CLA)

Engine preparations

- Operational characteristic should be with in 5 % from stock results
- Engine must be wormed up to manufactory specs.

Exhaust Emission Test Sequence Measurement Procedure (B cycle)

- Steady state test mode for rated speed applications
  1. 100% load - at least 2 minutes
  2. 75% load - at least 2 minutes
  3. 50% load - at least 2 minutes
  4. 25% load - at least 2 minutes
  5. 10% load - at least 2 minutes
  6. 0% Idle - at least 2 minutes
- Engine should be run for a sufficient time period to achieve thermal stability for each mode (cylinder temps)
- Calculated emissions shall be averaged over the test period
- Engine operating and performance parameters must be measure during each test.

Appendix H

Average of Tier 2 emission tests

Mode 1 emissions calculations

	Grams	G/Kw hr	G/Bhp hr
HC	527.17	40.35	30.09
CO	4.94	0.38	0.28
CO2	12509.21	957.45	713.97
NOX	147.71	11.30	8.43
O2	381363.18	29188.51	21765.85

Mode 2 emissions calculations

	Grams	G/Kw hr	G/Bhp hr
HC	338.98	31.45	23.45
CO	2.74	0.25	0.19
CO2	9298.87	862.74	643.34
NOX	158.31	14.69	10.95
O2	264424.14	24530.59	18292.43

Mode 3 emissions calculations

	Grams	G/Kw hr	G/Bhp hr
HC	201.74	26.99	20.13
CO	1.54	0.21	0.15
CO2	7473.04	1000.06	745.75
NOX	140.75	18.82	14.03
O2	200272.05	26797.99	19983.23

Mode 4 emissions calculations

	Grams	G/Kw hr	G/Bhp hr
HC	93.66	24.61	18.35
CO	0.61	0.16	0.12
CO2	4892.43	1285.28	958.43
NOX	57.07	15.00	11.18
O2	122731.20	32242.65	24043.31

Mode 5 emissions calculations

	Grams	G/Kw hr	G/Bhp hr
HC	56.18	38.74	28.89
CO	0.45	0.31	0.23
CO2	4394.53	3034.95	2263.16
NOX	24.91	17.20	12.83
O2	108506.12	74928.66	55874.23

Mode 6 emissions calculations

	Grams	G/Kw hr	G/Bhp hr
HC	42.48	131.97	98.41
CO	0.11	0.34	0.26
CO2	1608.23	5026.72	3748.42
NOX	5.54	16.90	12.60
O2	42473.44	132839.47	99058.26

Appendix H

Average of E-10 emission tests

Mode 1 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	420.85	32.04	23.89
CO	3.37	0.26	0.19
CO2	11643.03	886.39	660.98
NOX	180.94	13.77	10.27
O2	316557.42	24099.29	17970.81

Mode 2 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	263.65	24.44	18.23
CO	1.93	0.18	0.13
CO2	9285.73	861.01	642.05
NOX	220.89	20.48	15.27
O2	238809.5 4	22140.8 8	16510.4 3

Mode 3 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	158.26	20.77	15.49
CO	1.04	0.14	0.10
CO2	7132.88	936.57	698.40
NOX	172.69	22.68	16.91
O2	341574.7 5	44600.83	33258.79

Mode 4 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	76.61	19.74	14.72
CO	0.46	0.12	0.09
CO2	5207.20	1342.58	1001.16
NOX	64.01	16.50	12.31
O2	124965.90	32221.30	24027.39

Mode 5 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	36.63	24.10	17.97
CO	0.28	0.18	0.14
CO2	4307.01	2832.66	2112.31
NOX	26.33	17.32	12.91
O2	101656.4 2	66858.2 3	49856.1 2

Mode 6 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	29.76	131.64	98.16
CO	0.05	0.23	0.17
CO2	1662.77	7041.11	5250.55
NOX	5.81	24.47	18.25
O2	42129.24	178371.0 2	133011.0 9

Appendix H

Page 3

Average of E-20 emission tests

Mode 1 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	343.08	25.84	19.27
CO	2.45	0.18	0.14
CO2	11593.59	873.07	651.05
NOX	266.01	20.03	14.94
O2	297409.77	22397.20	16701.57

Mode 2 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	218.13	20.23	15.08
CO	1.25	0.12	0.09
CO2	9037.18	838.03	624.92
NOX	325.27	30.16	22.49
O2	220101.65	20410.22	15219.88

Mode 3 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	123.46	16.52	12.32
CO	0.62	0.08	0.06
CO2	6913.86	924.96	689.74
NOX	214.40	28.68	21.39
O2	163782.42	21911.89	16339.68

Mode 4 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	47.75	12.39	9.24
CO	0.24	0.06	0.05
CO2	5374.35	1396.58	1041.43
NOX	70.94	18.43	13.75
O2	122144.70	31729.99	23661.02

Mode 5 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	24.41	16.45	12.27
CO	0.11	0.08	0.06
CO2	4154.00	2800.11	2088.04
NOX	27.74	18.70	13.94
O2	93664.29	63130.73	47076.52

Mode 6 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	33.33	183.99	137.20
CO	0.03	0.16	0.12
CO2	1709.75	9441.98	7040.87
NOX	5.97	32.99	24.60
O2	43454.07	239914.79	178904.22

Appendix H

Average of E-85 CARB emission tests

Mode 1 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	180.81	13.24	9.87
CO	2.13	0.16	0.12
CO2	10250.76	750.40	559.57
NOX	224.05	16.40	12.23
O2	283784.41	20776.01	15492.65

Mode 2 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	120.69	10.40	7.76
CO	1.27	0.11	0.08
CO2	8538.60	735.95	548.79
NOX	323.22	27.85	20.77
O2	223558.17	19265.55	14366.30

Mode 3 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	54.93	6.73	5.02
CO	0.45	0.06	0.04
CO2	6269.96	768.61	573.15
NOX	188.44	23.08	17.21
O2	153700.99	18837.37	14047.01

Mode 4 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	23.81	6.02	4.49
CO	0.17	0.04	0.03
CO2	4274.69	1079.11	804.69
NOX	45.87	11.57	8.63
O2	104697.91	26433.72	19711.60

Mode 5 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	9.39	5.69	4.25
CO	0.08	0.05	0.04
CO2	3498.47	2120.68	1581.39
NOX	9.59	5.82	4.34
O2	56654.44	34365.60	25626.39

Mode 6 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	149.77	890.02	663.69
CO	0.34	2.02	1.51
CO2	1110.77	6625.24	4940.44
NOX	1.58	9.24	6.89
O2	41019.27	244507.68	182329.13

Average of E-85 Mod Head emission Tests

Mode 1 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	252.06	18.89	14.09
CO	2.15	0.16	0.12
CO2	9807.19	735.17	548.22
NOX	150.62	11.29	8.42
O2	257923.10	19336.01	14418.84

Mode 2 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	171.58	15.36	11.45
CO	1.15	0.10	0.08
CO2	7688.38	688.41	513.35
NOX	191.88	17.19	12.82
O2	193690.56	17340.95	12931.13

Mode 3 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	112.08	14.41	10.75
CO	0.52	0.07	0.05
CO2	5685.20	731.21	545.26
NOX	113.27	14.57	10.86
O2	137217.63	17646.07	13158.66

Mode 4 emission calculation

	Grams	G/Kw hr	G/Bhp hr
HC	55.42	14.13	10.54
CO	0.14	0.04	0.03
CO2	3909.83	997.86	744.10
NOX	29.18	7.44	5.55
O2	89561.60	22856.22	17043.86

Mode 5 emission calculation

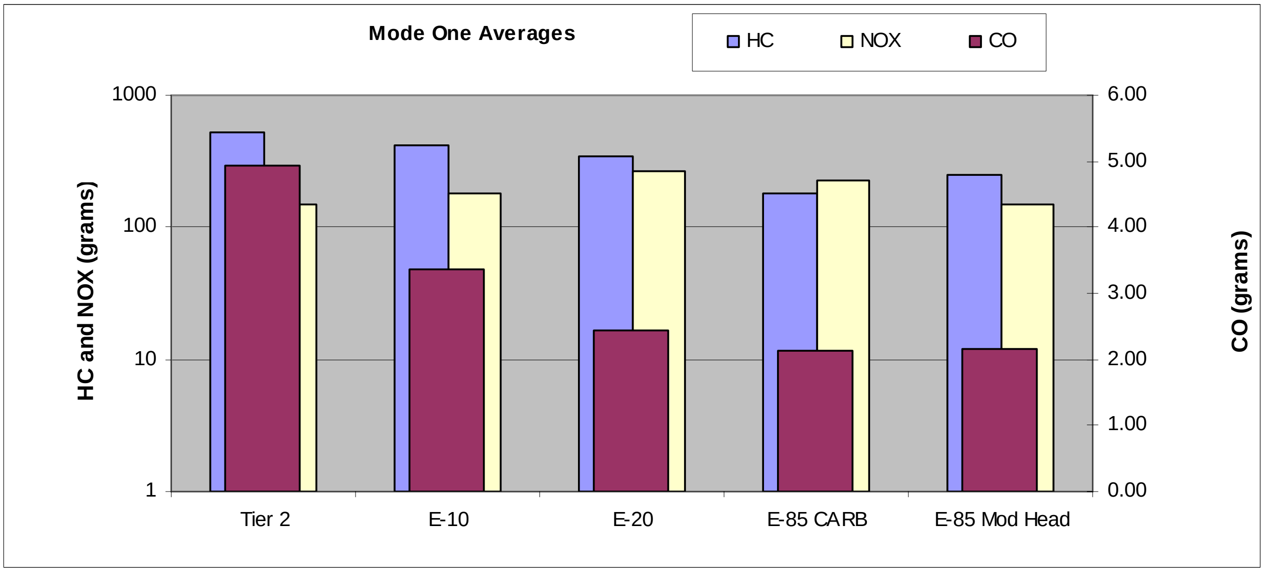
	Grams	G/Kw hr	G/Bhp hr
HC	39.68	25.45	18.97
CO	0.14	0.09	0.07
CO2	3114.41	1998.29	1490.12
NOX	8.29	5.29	3.94
O2	73011.42	46852.89	34938.15

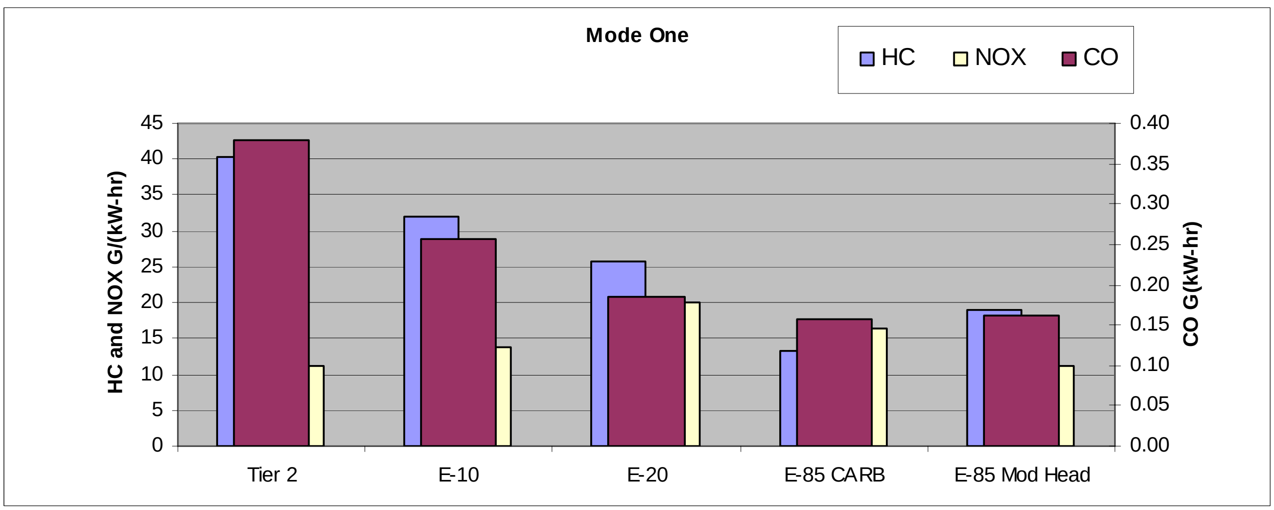
Mode 6 emission calculation

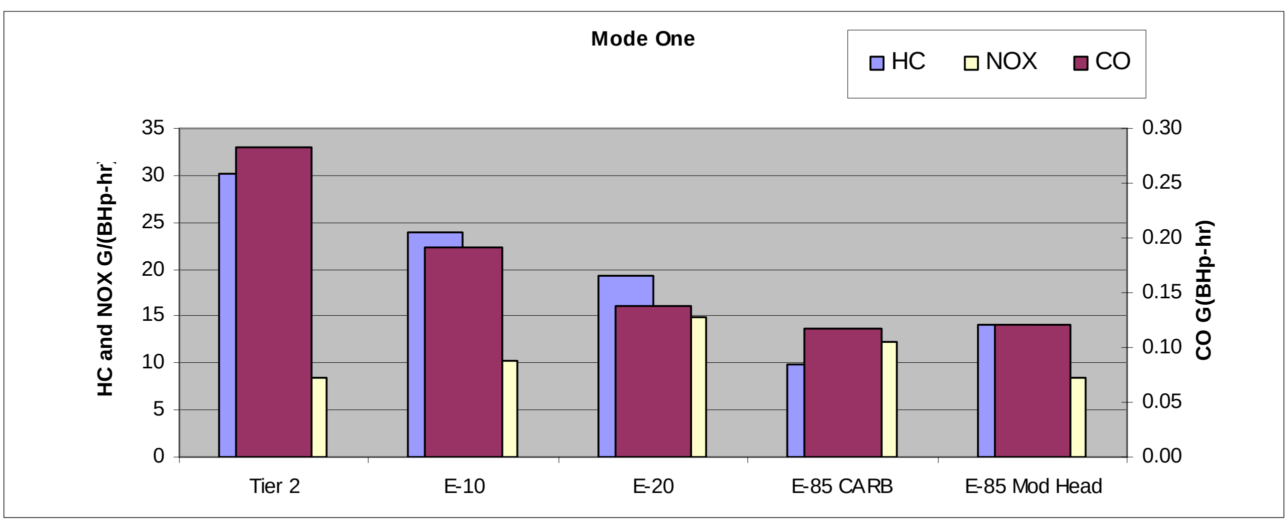
	Grams	G/Kw hr	G/Bhp hr
HC	101.13	533.90	398.13
CO	0.23	1.22	0.91
CO2	1523.14	8031.63	5989.18
NOX	1.79	9.45	7.04
O2	41983.48	221399.11	165097.10

Appendix I

Mode 1 Averages







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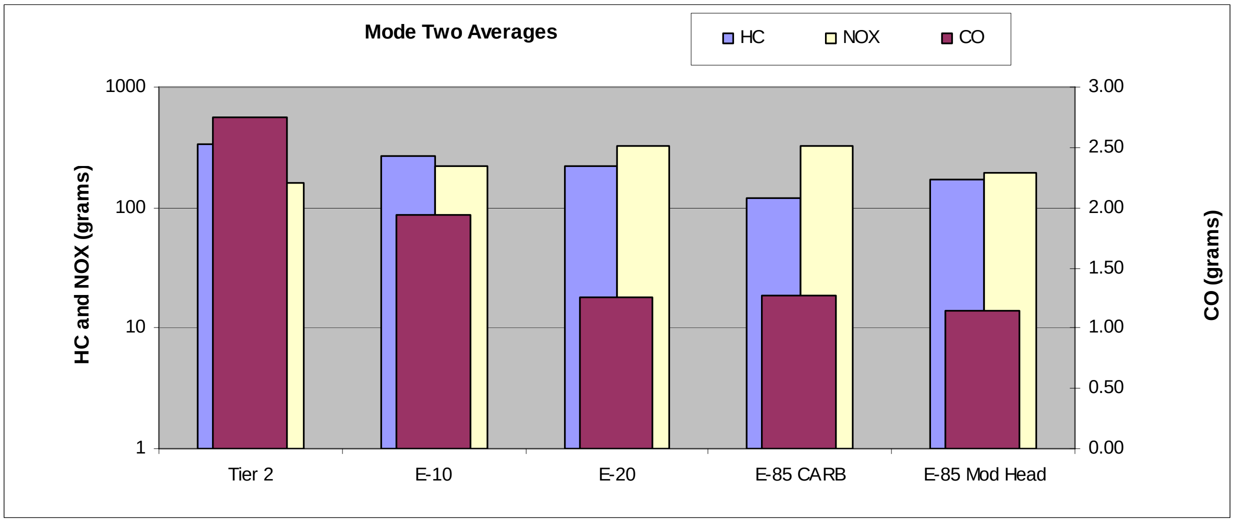
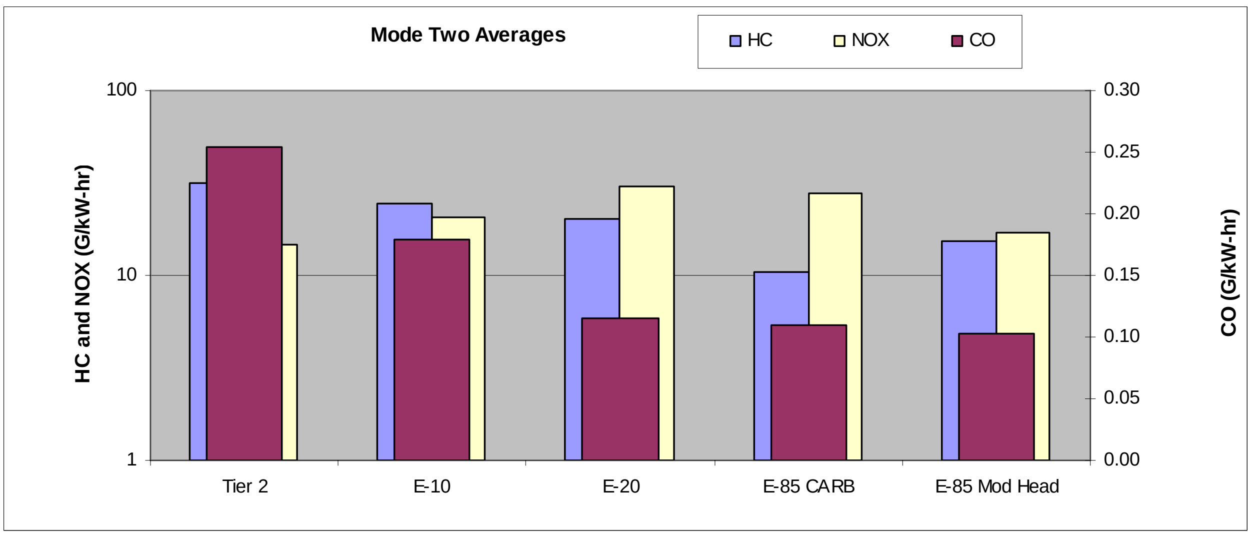
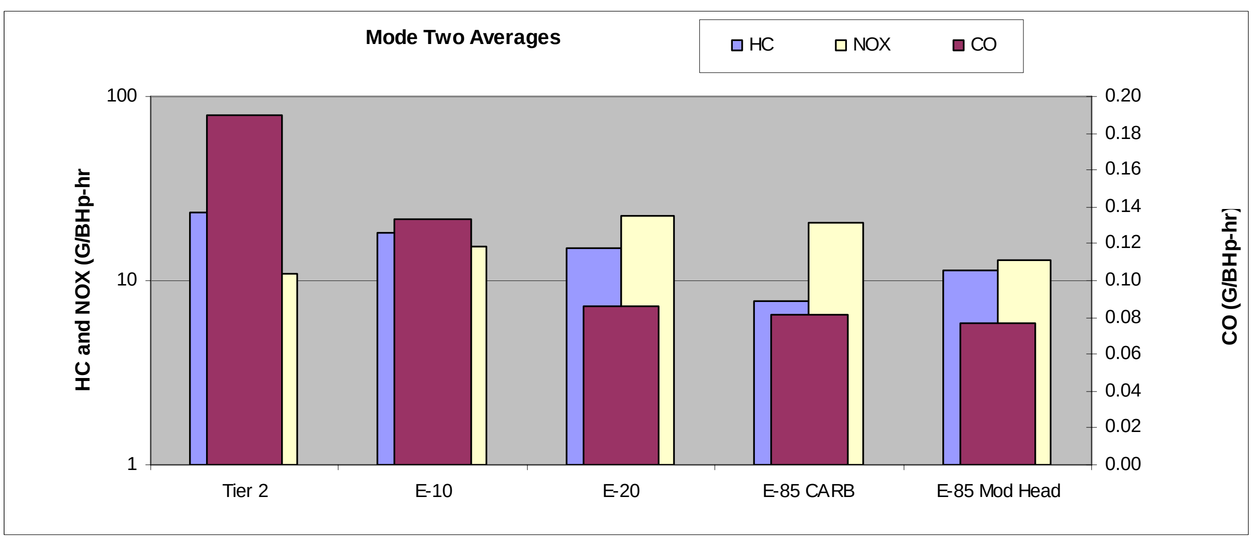
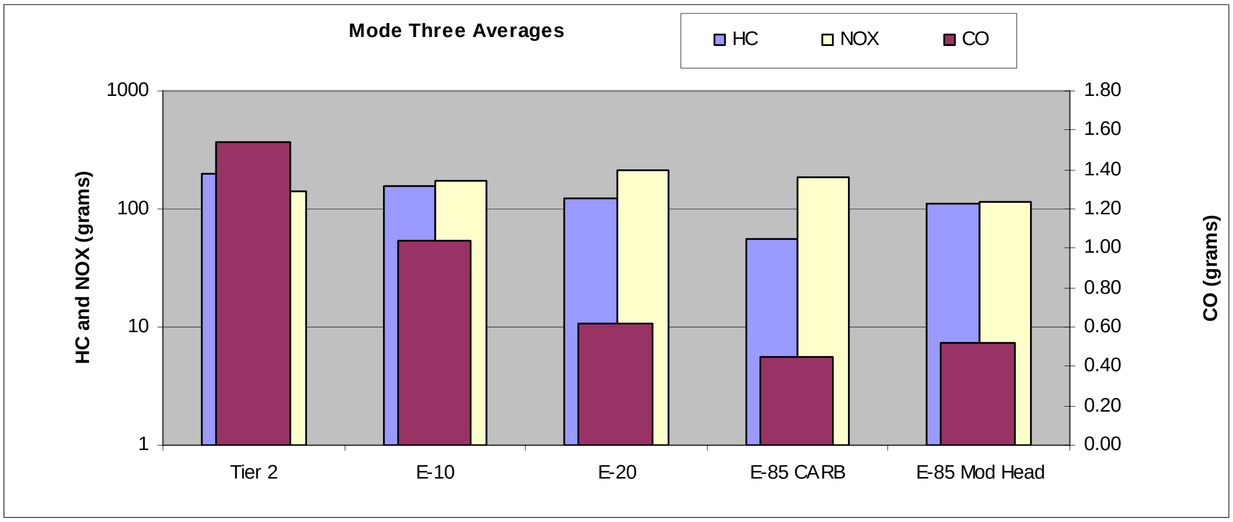


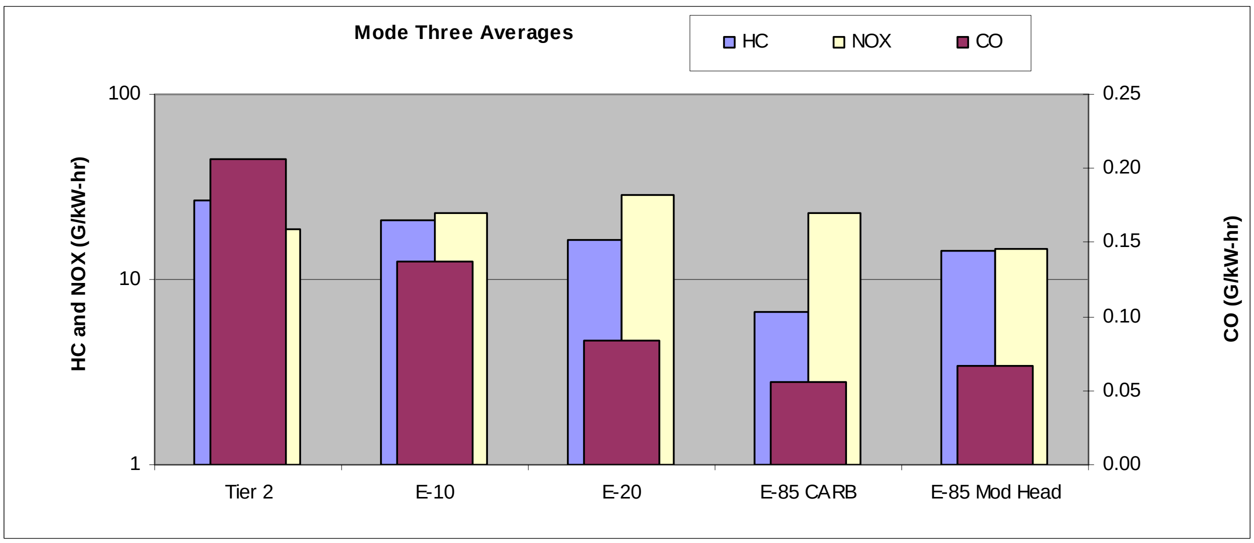


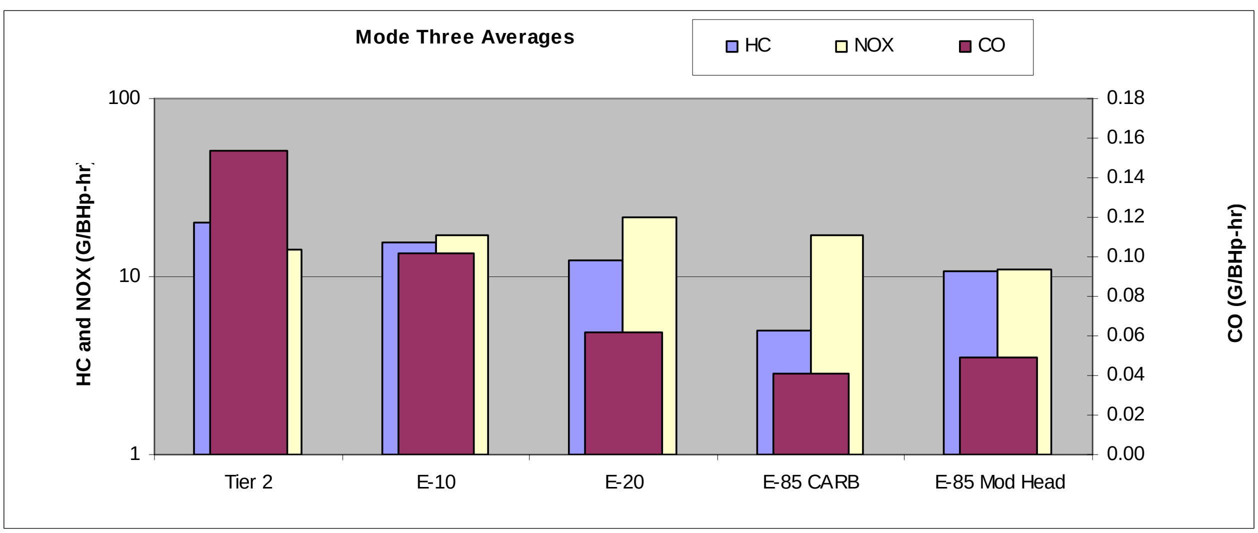


Appendix I

Mode 3 Averages

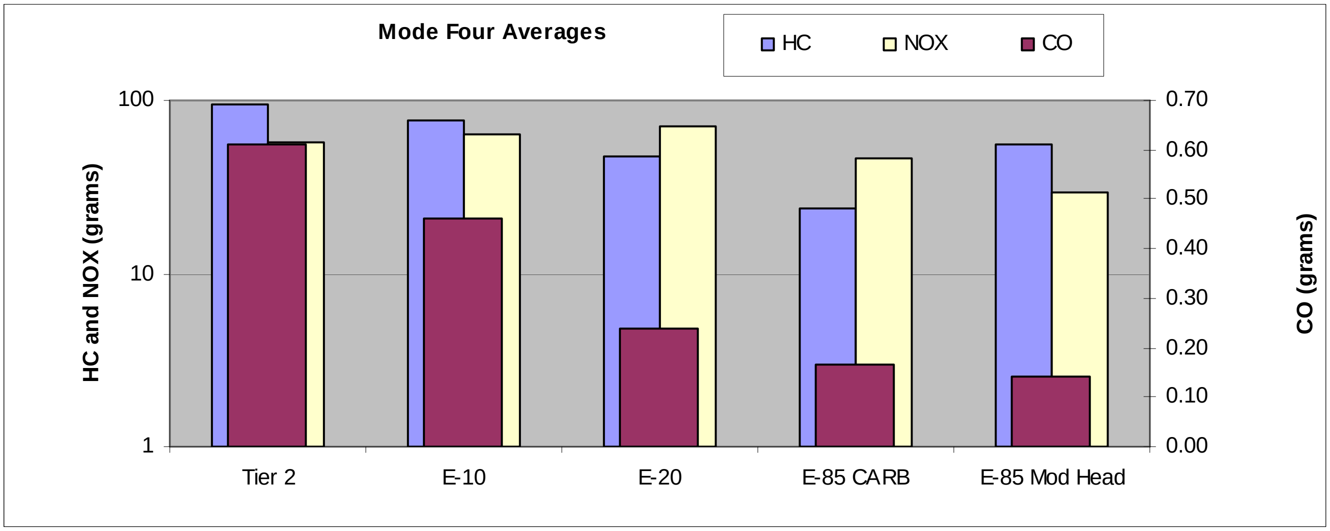


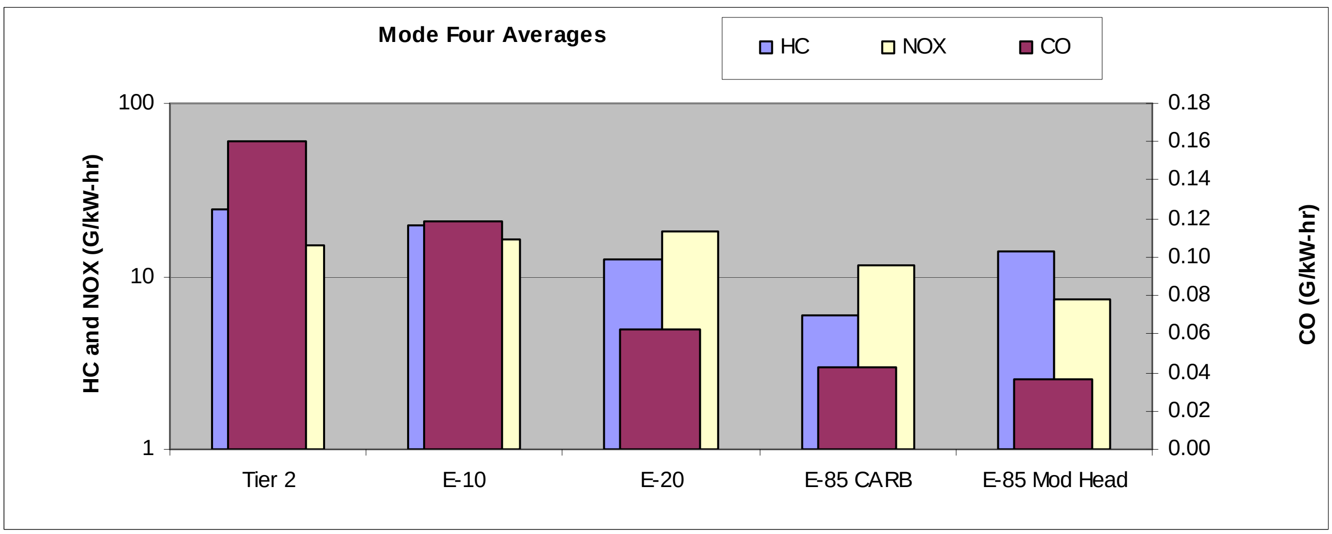


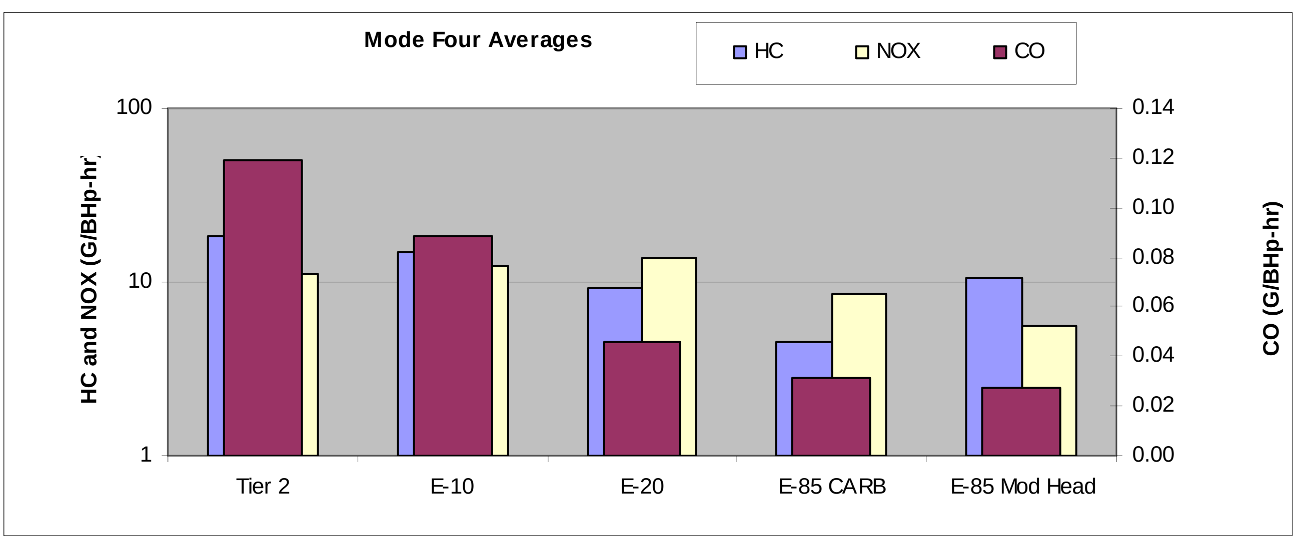


Appendix I

Mode 4 Averages

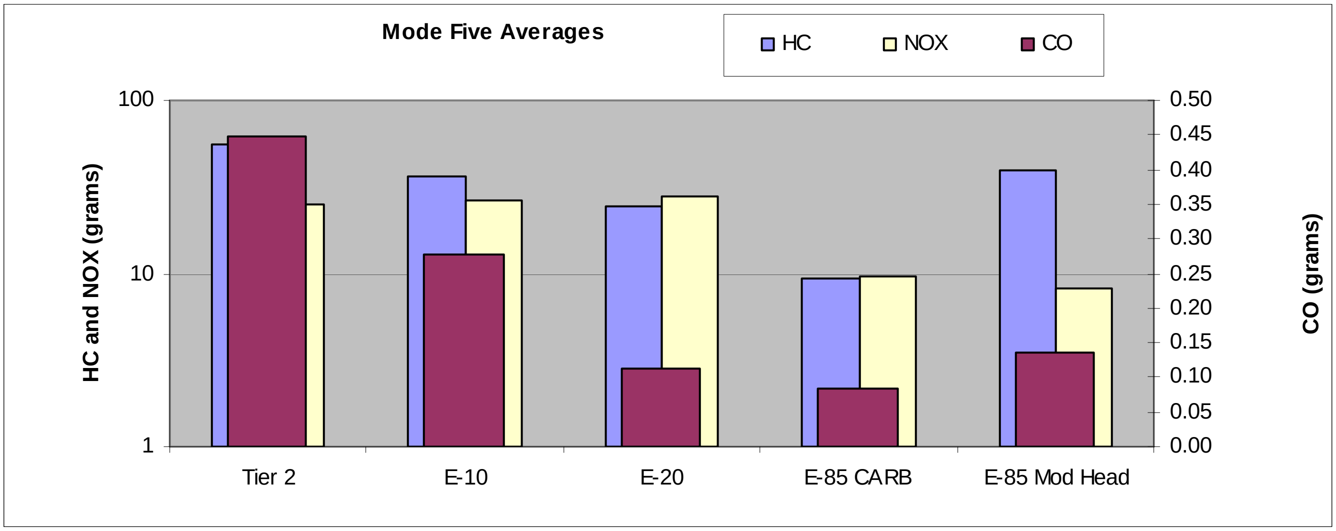


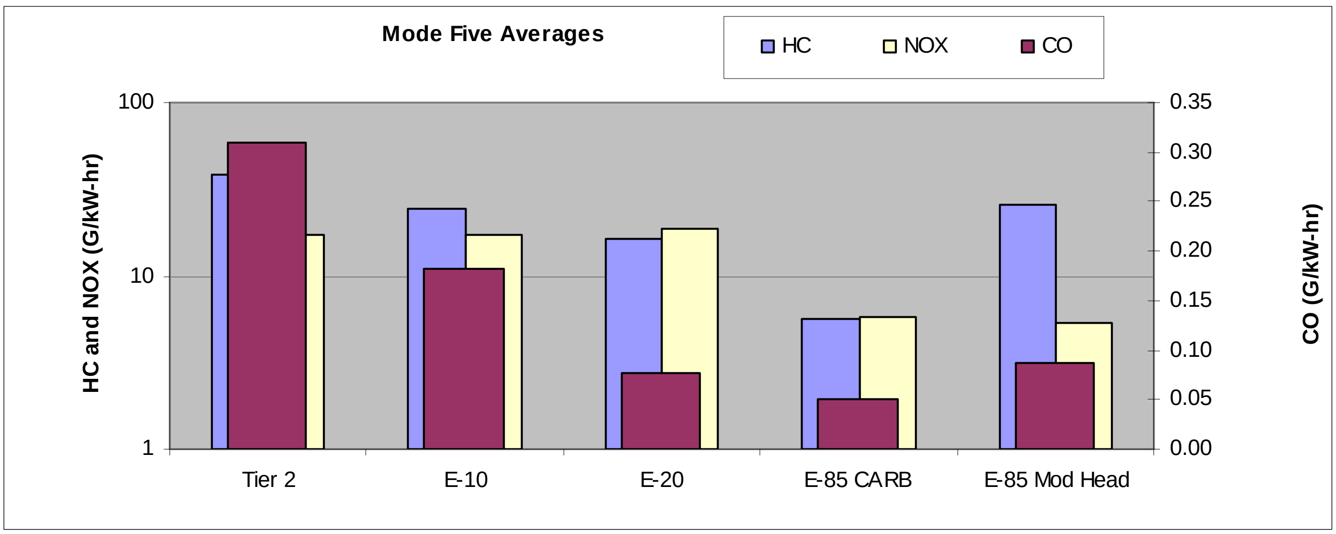


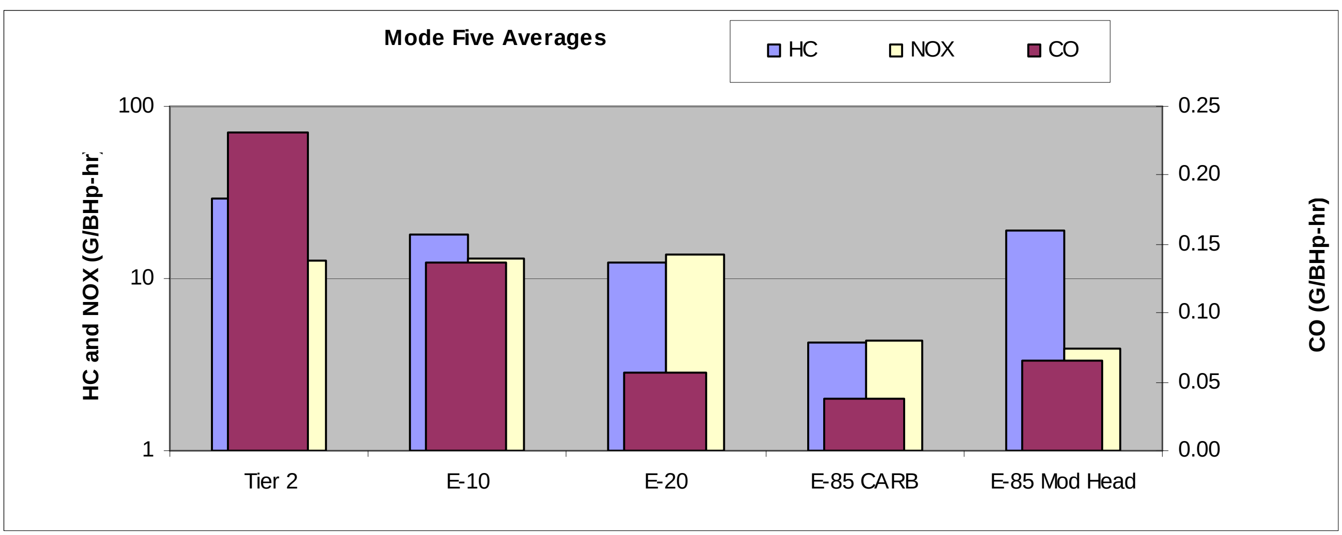


Appendix I

Mode 5 Averages

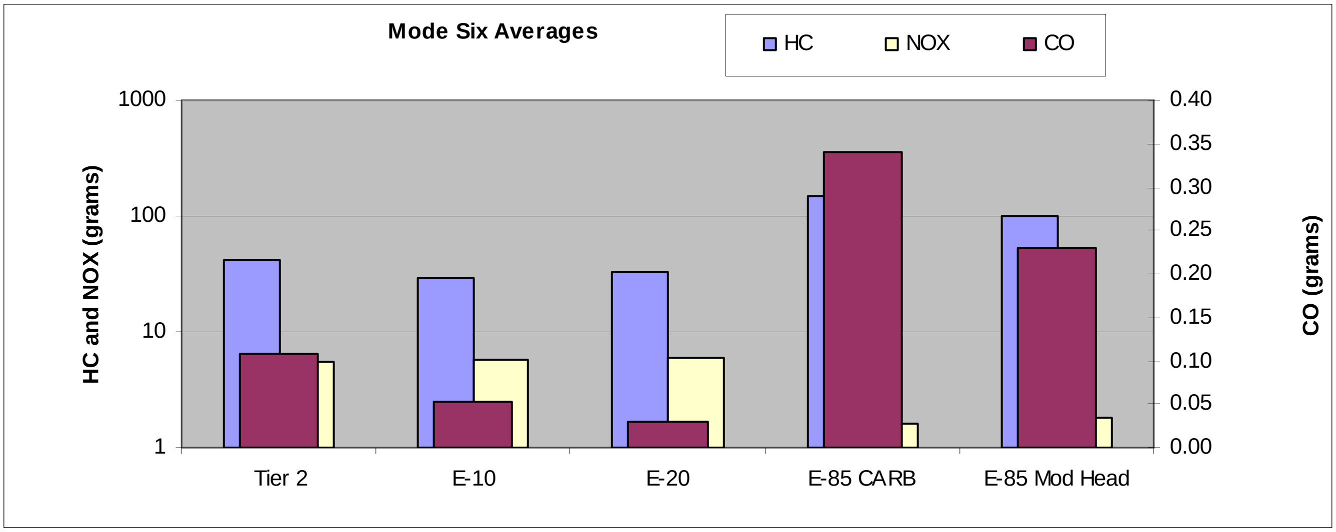


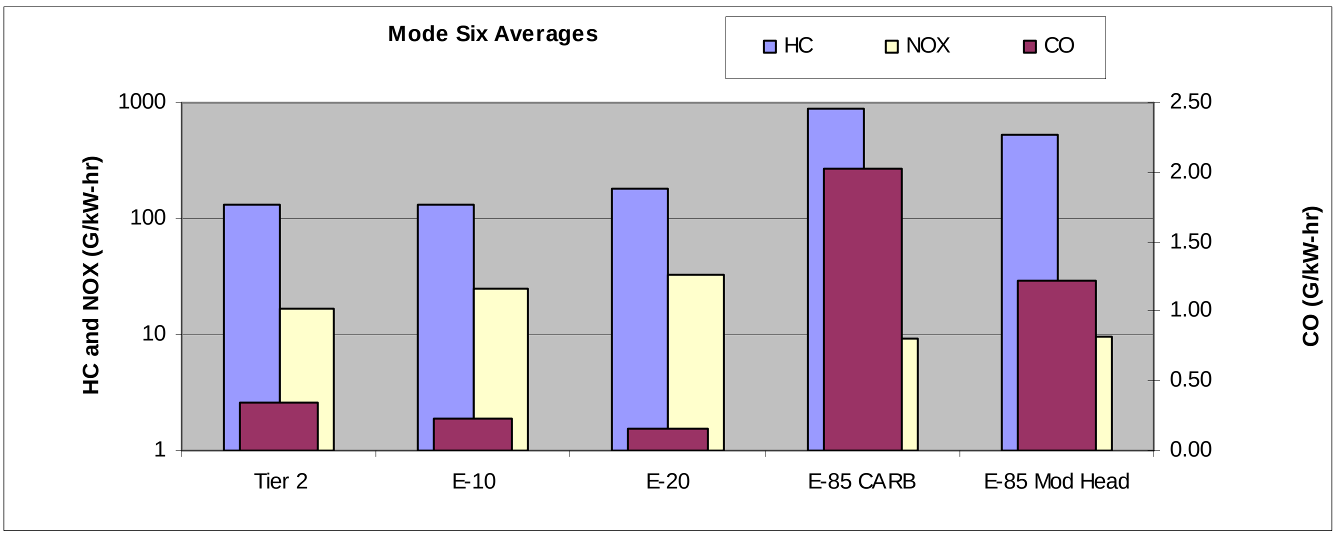


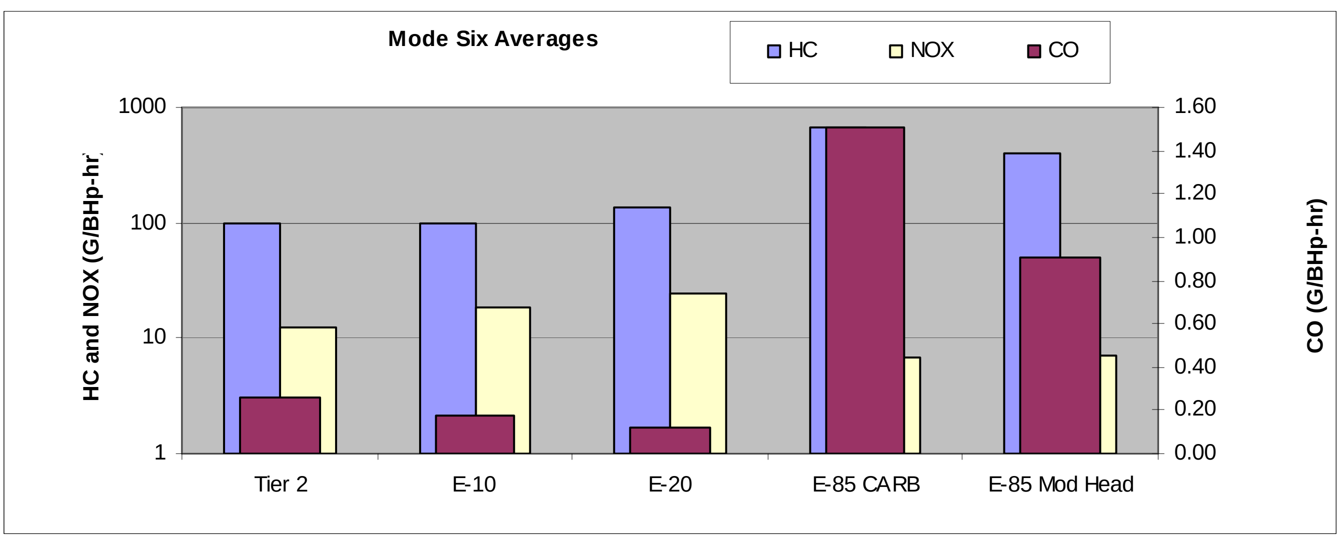


Appendix I

Mode 6 Averages

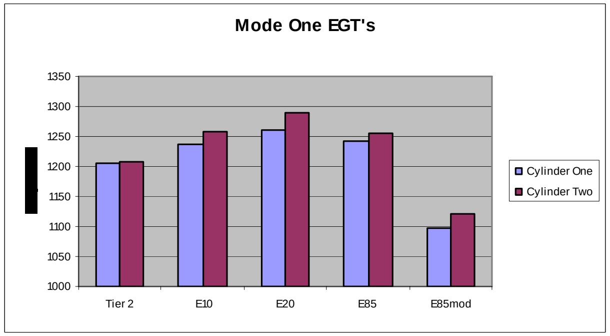


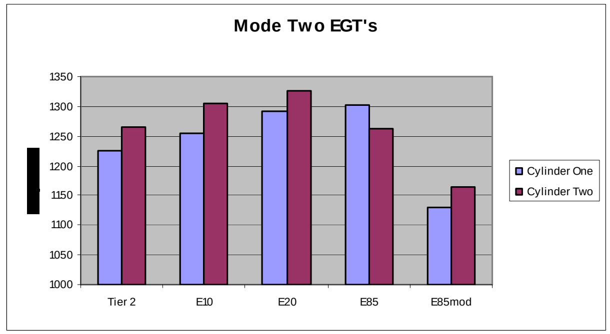


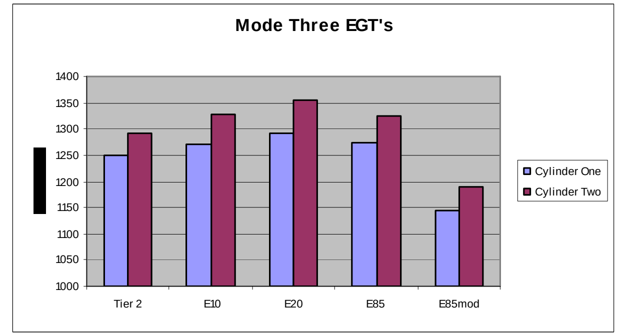


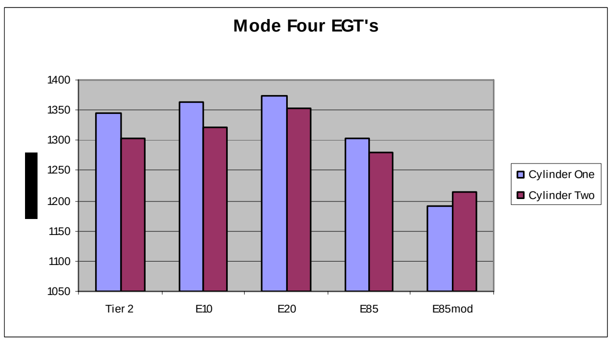
Appendix J

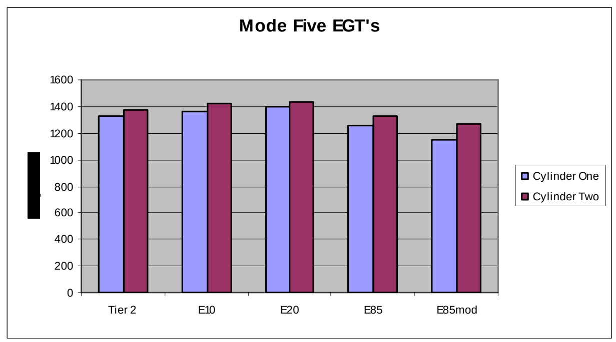
Emission Modes
Exhaust Gas Temperature Average

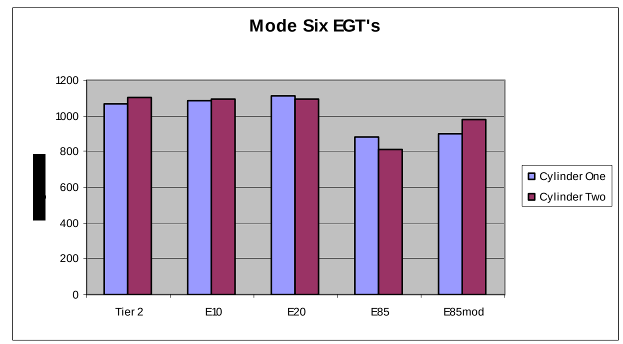












Appendix K

Emission Modes
Cylinder Head Temperature Average