AN INVESTIGATION OF THE EXHAUST EMISSIONS, FUEL ECONOMY, AND DRIVEABILITYOF A 1997 CHEVROLET MALIBU FUELED WITH GASOLINE, 10% ETHANOL/90% GASOLINE, AND 20% ETHANOL/80% GASOLINE

by

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A thesis submitted in partial fulfillment of the
Requirements for the Degree of Master of Science
In Manufacturing Engineering Technology

Minnesota State University, Mankato
Mankato, Minnesota
July 2006

Date__________________________________

This thesis paper has been examined and approved.

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ACKNOWLEDGEMENTS

I would like to recognize a number of people who have contributed to the successful completion of this thesis. First of all, I would like to thank my immediate supervisor, Dr. Bruce Jones, for his guidance and encouragement throughout the different stages of this project. I would like to thank my graduate committee and the faculty and staff in the Automotive and Manufacturing Engineering Technology Department for their technical support and advice. Special thanks goes to my advisor, Dr. Harry Petersen, for his effort in helping me return to school after such a long break, and helping iron out the kinks a graduate degree presents. I would also like to thank Dr. Mark Zuiker, professor of applied statistics in the Minnesota State University, Mankato Math Department for his help with the statistical analysis of results.

Finally, I would like to thank my family for their support throughout this endeavor, especially my wife Laura. Without her unconditional and never ending support this would not have been possible.

Abstract

This was a one year study comparing the effects of gasoline, and blends of E10 and E20 on the tailpipe emissions, fuel economy, and driveability characteristics of a 1997 Chevrolet Malibu. The testing was divided into two categories; emissions/fuel economy, and driveability. For the emissions/fuel economy testing, five EPA 78 drive cycle tests, and five Highway Fuel Economy tests were performed using each fuel. The gasoline used for the emissions/fuel economy testing was EPA Tier II EEE gasoline, commonly known as Indolene. The E10 blend consisted of 10% ethanol and 90% Tier II EEE gasoline and the E20 blend consisted of 20% ethanol and 80% Tier II EEE gasoline. The driveability of the vehicle was assessed using the Coordinating Research Council (CRC) Revised Cold-Start and Warm-Up Procedure. The base fuel for the driveability testing was a regular grade 87 octane non-oxygenated gasoline purchased from a large volume retail supplier. The ethanol used in this study was neat ethanol with no denaturant.

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CHAPTER I

Introduction

The Clean Air Act Amendments, enacted November 15, 1990, updated the original Clean Air Act and provided the framework for major advances in control of air quality in those areas of the United States most in need of cleaner air. One portion of the Clean Air Act Amendments called for cleaner automotive fuels. This appeared to open the door for increased use of alternative fuels, such as natural gas, methanol, propane, electricity, and the subject of this report, ethanol. The Clean Air Act Amendments of 1990 mandated the use of oxygenated gasoline in areas with unhealthy levels of carbon monoxide. At the time, the primary oxygenates were ethanol and Methyl Tertiary Butyl Ether (MTBE). Subsequently, MTBE has been shown to contaminate ground water supplies, and the demand for ethanol has increased significantly (Clean Cities 2005). Ethanol is an alcohol-based alternative fuel produced by fermenting and distilling starch crops that have been converted into simple sugars. Ethanol can be produced from a variety of feed stocks, such as sugar cane, sugar beet, sorghum, switch grass, barley, potatoes, corn, grain, and wheat, as well as many types of cellulose waste (Wagner, Gray, Zarah, Kozinski 1979).

The Energy Policy Act of 1992 (Public Law 102-486) was passed by Congress to reduce our nation's dependence on imported petroleum by requiring certain fleets to acquire alternative fuel vehicles, which are capable of operating on nonpetroleum fuels. In the United States, one out of every eight gallons of gasoline sold contains ethanol.

Most of this ethanol is purchased as blends of 10% ethanol and 90% gasoline, known as E10, and is used as an octane enhancer to improve air quality (Fuel Blends 2005).

Ethanol already had a history of use as an alternative fuel in the United States and other countries. In the United States, significant use of ethanol as an auto fuel began with the enactment of the Energy Tax Act of 1978 (Public Law 96-618) which exempted ethanol blends from part of the Federal highway tax (Lazzari 2001). Ethanol production increased, as reported by Segal (1993):

> The blend of 10 percent ethanol to 90 percent gasoline, originally known as gasohol, increased in sales from zero in 1978 to about eight billion gallons in 1985 and remained at roughly that level through 1991. In 1992 sales rose to about 10.5 billion gallons, spurred by the increased use of ethanol (as well as other oxygenates) for control of carbon monoxide (p. 5).

There continues to be interest from corn growers who envision a huge new market for their crops and from politicians who see the ethanol industry as a way to improve local and regional economies (Economist 2005).

Reid Vapor Pressure

As stated earlier, the Clean Air Act of 1990 called for cleaner automotive fuels in order to upgrade air quality. This appeared to provide new market potential for ethanol. The Clean Air Act Amendments and the subsequent regulations are primarily intended to prevent ozone formation, as ozone is a major contributor to urban smog (Aulich, He, Grisanti, Knudson, 1994). Carbon monoxide (CO) is another important air pollutant, not related to ozone. When Congress passed the 1990 Clean Air Act Amendments about 40 areas of the United States were not in compliance with the ambient CO standard, mostly in the winter, when Congress passed the 1990 Clean Air Act Amendments (Knapp, Stump, Tejada, 1995). The amendments required that these areas must implement programs to reduce winter vehicle CO emissions. One approach that the U.S. Environmental Protection Agency took was to require oxygen in the gasoline used in the winter in those areas not in compliance. This was known as the oxy-fuel program. It required adding an additive that contained oxygen to the gasoline. Ethanol is quite effective in reducing carbon monoxide pollution, and has been used for that purpose in many Western cities. With regard to ozone reduction, however, the picture is less clear. When ethanol is added to gasoline in the 10% blend generally used, the volatility of the mixture is higher than the original gasoline blend stock by about 1 pound per square inch (psi), as measured by the Reid Vapor Pressure (RVP) (Aulich, Crocker, 2000). Volatility is the property of a liquid fuel that defines its evaporation characteristics. RVP is an abbreviation for "Reid vapor pressure," a common measure of gasoline volatility, as well as a generic term for gasoline volatility. The EPA regulates the vapor pressure of all gasoline during the summer months from June 1 to September 15 (Gasoline Fuels, 2005). This means that the gasoline / ethanol blend has a greater tendency to evaporate than straight gasoline, and therefore that, other things being equal, more Volatile Organic Compounds (VOCs) would enter the atmosphere from the blend than from straight gasoline. Because RVP measures how easily a liquid evaporates, a higher RVP means that more of the fuel can evaporate contributing to the formation of ground-level ozone. To limit the possibility of such emissions the EPA has set progressively tighter limits on RVP in fuels. These rules reduce gasoline emissions of volatile organic compounds (VOC’s) that are a major contributor to ground-level ozone (smog). Depending on the state and month, gasoline RVP may not exceed 9.0 psi or 7.8 psi. EPA provides a 1.0 psi RVP allowance for gasoline containing ethanol at 9 to 10 volume percent (Gasoline Fuels, 2005).

Tests performed by the EPA have shown the RVP increase begins to reverse itself as the percentage of ethanol increases (Guerrieri, Caffrey, Rao, 1995). Although the point at which the RVP decreases is highly contingent upon the base fuel characteristics, Guerrieri et al. (1995) indicates that the RVP will begin decreasing with increased ethanol level around 17%-20% ethanol blend level, and will reach the original RVP of the gasoline alone at about 30% ethanol blend level. The base fuel used in this test was a non-oxygenated regular unleaded summertime fuel.

Fuel Control System

The fuel control system is critical to the normal operation and emission control of the vehicle. It is also sensitive to changes in fuel composition. For higher blends of ethanol to work well in a vehicle the fuel control system must be able to compensate for differences between ethanol blends and gasoline. Adding ethanol increases the oxygen content of the fuel mixture. This causes a computer controlled engine fuel management system to try to compensate and adjust the air / fuel ratio (A/F) back to stoichiometric. The stoichiometric A/F is the chemically correct ratio of air and fuel. This provides the correct amount of oxygen necessary for the complete conversion of all fuel into oxidized products (Orbital Engine Company, 2002). Oxygen content is measured by the vehicle computer by a sensor, called an oxygen sensor, in the vehicle exhaust system. The oxygen sensor voltage output changes with any change in the oxygen content in the exhaust. In this way the sensor supplies data, via different voltage signals, to the vehicle computer. The computer can then alter the amount of fuel delivered to the engine to maintain a stoichiometric air / fuel ratio (Duffy, 1990). If the system limits are reached the engine management system cannot maintain a stoichiometric A/F and the system will become increasingly lean as ethanol content increases (Guerriere et al. 1995). This problem is referred to as enleanment. Fuel control systems vary considerably depending on the year the vehicle was manufactured. Whether or not higher ethanol blends can be used in conventional vehicles without modification is a central question. The age of the vehicle, the vehicle manufacturer, and its emission control system type are highly important variables (Hammel-Smith, Fang, Powders, Aabakken, 2002).

Driveability

Drivers have an expectation of how a vehicle will operate under normal driving conditions. How well a vehicle conforms to this expectation can be defined as driveability. Jewitt, Gibbs, and Evans (2005) defined driveability in this way:

> Driveability describes how dependably and smoothly a vehicle responds to changes in throttle position under all kinds of weather and operating conditions. It describes how it starts, warms up, and runs. Driveability problems include hard starting, rough idle, and poor accelerator response (hesitation, stumble, surge, backfiring, and stalling). (p. 1)

When assessing drivability and the use of ethanol, the following factors are often considered; hot operation, cold-start, enleanment, and materials compatibility. During hot operation the potential for driveability problems exist with higher volatility fuels. The volatility of 10% ethanol blends is approximately 1 psi higher than unleaded gasoline. Vapor lock and difficult hot start can potentially occur more often using a fuel with a higher volatility, particularly in warmer temperatures. Issues related to cold-start arise due to the low volatility of ethanol. The RVP of ethanol is 2.3 psi compared to 7-15 psi for gasoline. However, cold start-up problems may not be indicated with higher than 10% ethanol blends if the RVP of the fuel is within the RVP range of gasoline (Hammel-Smith, et al. 2002). Enleanment may occur if a fuel control system is unable to adjust an A/F properly because of an excess of oxygen. An A/F that is too lean could result. Common problems when an engine is running very lean are loss of power and engine misfires, which could cause an increase in emissions (Hammel-Smith, et al. 2002).

Material Compatibility

Alcohol fuels have different physical and chemical properties than gasoline which affects their compatibility with fuel system components. The automotive industry has generally classified these components into three categories; plastics, elastomers (rubbers), and metals (Sun Refining and Marketing Company, 1988). Metals have been analyzed for rust, pitting, and deposit formation. A change in mass of a metal specimen has been used to determine the amount of corrosion. Elastomers and plastics have been analyzed for a change in volume (Miyawaki, Date, Akasaka, Maeda 1980).

Polymer permeability is another issue related to material compatibility. This is viewed as a major factor in evaporative emissions (Hammel-Smith, et al. 2002).

Emissions

Guerrieri, Caffrey, and Rao (1995) conducted a test of six vehicles on a base gasoline and nine gasoline/ethanol blends with ethanol content ranging from 10% to 40%. They found an inverse relationship between the ethanol content in the fuel and exhaust emissions of total hydrocarbons (THC), and carbon monoxide (CO) for all six cars. THC emissions decreased about 30% from base level while CO emissions decreased about 40% from base level. CO2 emissions changed very little from base level with a slight 1% increase from 0-20% ethanol and a slight 2% decrease from 25-40% ethanol. On the other hand, the test indicated a direct relationship between ethanol content and oxides of nitrogen (NOx) emissions. NOx emissions rose slightly for the E10 blend but rose approximately 25% higher for the E20 blend and continued to rise to almost 200% of base levels for the 40% ethanol blend. Similar results were found using average percentage changes in emissions from base level and ethanol content. Emissions of THC, and CO decreased as the ethanol content rose, while emissions of NOx rose with the percentage content of ethanol in the fuel blend. Emissions of carbon dioxide were only slightly affected by the ethanol content in the fuel (Guerrieri, et al. 1995).

Problem Statement

The main purpose of this study is to determine if differences in exhaust emissions and driveability exist between gasoline, E10 (10% ethanol/90% gasoline), and E20 (20% ethanol/80% gasoline) when these fuels are used in a 1997 Chevrolet Malibu. Based on the information discussed in the previous sections three hypothesis will be tested.

Hypothesis 1: It is hypothesized that hydrocarbon and carbon monoxide emissions will decrease, nitrogen oxide emissions will increase, and carbon dioxide emissions will not change significantly as ethanol content increases.

Hypothesis 2: It is hypothesized that there will be no driveability difference using the unmodified test vehicle and all three fuel types.

Hypothesis 3: It is hypothesized that fuel economy will change as a function of the energy content of the fuel.

CHAPTER II

Method

Emission / Fuel Economy Test Design

The EPA 78 Federal Test Procedure (FTP), specified in the Code of Federal Regulations (CFR) Title 40 CFR 86.115-78, was used to conduct the emission tests for each fuel type and to determine in-city fuel economy. The EPA Highway Fuel Economy Trace (HWFET), specified in 40 CFR 600.109-78, was used to conduct highway fuel economy testing.

The test program was designed to measure total hydrocarbon emissions (THC), carbon monoxide emissions (CO), carbon dioxide emissions (CO2), nitrogen oxide emissions (NOx), and fuel economy (MPG). Three fuels were used for testing. The baseline fuel for emission and fuel economy testing was EPA Tier II EEE gasoline (Tier II gasoline) specified in 40 CFR 86.113-04. This fuel is commonly known as Indolene. Two ethanol blends of 10% (E10) and 20% (E20) ethanol were also tested. The two ethanol blends consisted of 10% Ethanol / 90% Tier II gasoline, and 20% ethanol / 80% Tier II gasoline. Ethanol for this project was obtained directly from the manufacturer and was not denatured with any gasoline. Five tests were performed using each fuel type. It was determined that no less than five tests per fuel would be performed after reviewing other studies of a similar nature, and it was determined that no more than five tests per fuel would be performed due to the additional time and cost associated with each additional test. Emissions data and fuel economy data were gathered during each of the five tests.

Emission / Fuel Economy Test Vehicle

The test vehicle was a 1997 Chevrolet Malibu, VIN # 1G1ND52M6VY100077, with a 3.1 liter V-6 engine and automatic transmission. This vehicle had previously been used in the 1998 Ethanol Vehicle Challenge sponsored by the U.S. Department of Energy and General Motors. Significant modifications were made by a group of Minnesota State University, Mankato students to optimize the operation of the vehicle on E85. Prior to any testing, or preconditioning, the vehicle engine was replaced with the original, unmodified engine. The catalytic converter and fuel pump were replaced with new, original equipment parts obtained from a GM dealer. The vehicle was then driven a total of 5,500 miles using regular unleaded gasoline from various gas stations throughout the Midwestern states to season the catalytic converter according to 40 CFR 86.000-26. No modifications were made to the vehicle to adapt to the higher than normal oxygen content of the fuel.

Emission / Fuel Economy Preconditioning Procedure

Prior to the collection of exhaust emissions for each fuel type the vehicle was preconditioned to reset the fuel tables in the vehicle Powertrain Control Module (PCM) for the new fuel type. The first of these was a 13 mile on road drive cycle consisting of in city and highway driving conditions. The second and third drive cycles consisted of driving the EPA 78, LA4 drive trace on the SuperFlow chassis dyno in the Minnesota Center for Automotive Research (MnCAR) lab. It was determined that the PCM would learn twice as fast during the first two drive cycles if the fuel trim tables were reset using a scanner (Brady 2001). It was decided that the vehicle engine water temperature should be allowed to cool below 160 degrees F prior to performing a fuel trim relearn drive cycle, and then rise at least 40 degrees F, so that each drive cycle would comply with the OBD II definition of a warm up cycle (Halderman, Linder 2006). It was noted after the E10 testing that if the vehicle was allowed to soak for 12 hours prior to each preconditioning drive cycle, the fuel tables stabilized faster. This is apparent when looking at the test data obtained during the emission tests. The E10 testing required a total of seven tests to obtain a series of five tests with consistent results. The first two E10 tests show that the fuel economy was still changing. This indicated that the fuel tables in the PCM had not stabilized and, that the fuel trim relearn process was not complete. The preconditioning process was then changed to include a 12 hour, room temperature, soak period. The fuel tank was completely drained of the previous fuel and filled with the test fuel according to the Coordinating Research Council (CRC) Fuel Tank Flushing Procedure (Coordinating Research Council, 2004). A copy of this procedure can be found in Appendix A. During the preconditioning process a Tech II vehicle computer diagnostic scan tool was used to reset the fuel trim and monitor the stabilization of the PCM fuel tables.

Emission / Fuel Economy Test Equipment

A California Analytical Instruments dilution type emission analyzer with a critical flow venturi rated at 350 cfm was used to record exhaust emissions. The dynamometer was a SuperFlow AC current dyno with two 13 inch diameter rolls. There are some notable differences between the equipment used for testing and the equipment specified in 40 CFR 86.108-00 for emission testing.

The CFR specifies the use of equipment which will capture a sample of the exhaust emissions for each of the three phases in the FTP cycle. The exhaust sample is placed into a Mylar bag to be analyzed after the test has been completed. In addition, an ambient air sample is captured during each phase so the amount of emissions present during the test can be subtracted from the tailpipe sample. It also specifies a dynamometer with a single 48 inch diameter roll.

The emission analyzer in the MnCAR lab does not use bag sampling. Instead it measures the ambient air just before a test for any background emissions. The background emissions are then subtracted from the end results to obtain the actual emissions produced by the test vehicle. The tailpipe emission levels are measured every second during each phase of the test and the results are then integrated to obtain the results.

Emission / Fuel Economy Test Procedure

The EPA 78 Federal Test Procedure (FTP) was used to conduct the emission tests and the highway fuel economy drive cycle (HWFET) was used to measure fuel economy for each fuel type. The EPA 78 test consists of three phases. Phase 1 begins with a cold engine and lasts for 505 seconds. Phase 2 immediately follows Phase 1 and lasts for 880 seconds. Phase 1 and Phase 2 constitute the 23 minute, LA 4, driving cycle. This is followed by a 10 minute hot soak period and then Phase 3 begins. Phase 3 is the same drive cycle as Phase 1 but is conducted with a hot engine.

Driveability Test Design

The driveability test is based on the Coordinating Research Council Revised Cold-Start and Warm-Up Driveability Procedure (Coordinating Research Council, 2004). A copy of this procedure can be found in Appendix B. This is an intermediate temperature test conducted at temperatures between 30 – 40 degrees Fahrenheit. The test procedure contains a series of maneuvers which idle the engine and require light and medium acceleration and steady state conditions, and wide open throttle accelerations. Two tests were performed using each fuel. Three fuels were used for testing; gasoline, E10, and E20. A total of ten tests were performed. Tests were conducted using each fuel after the PCM was allowed to learn the fuel. A worst case scenario test was also conducted to determine the effect on driveability when the PCM was not allowed to learn the fuel. One driver performed all tests due to the subjective nature of this type of test. Due to the fact that only one vehicle was used during driveability testing the results were not statistically analyzed.

Driveability Test Program

Testing was performed according to the CRC Revised Cold-Start and Warm-Up Driveability Procedure. Two different tests were conducted to determine the effect the fuels had on driveability. Each fuel was tested after a preconditioning process which allowed the PCM to learn that specific fuel. A worst case scenario test was also performed to determine the effect on driveability when the PCM was not allowed to learn the fuel. This was only done using gasoline and E20. The worst case scenario was intended to simulate what may occur when a vehicle that was previously fueled with gasoline refueled with E20, and then sat for several hours before being driven again. For this test the vehicle was allowed to learn gasoline, the vehicle fuel tank was drained according to the CRC Fuel Tank Flushing Procedure, and the vehicle was refueled with E20. The vehicle was then allowed to sit for at least 12 hours. The driveability test was then conducted. This test was also done after the vehicle had learned E20 and was refueled with gasoline. Two worst case scenario tests were performed using gasoline, and two tests were performed using E20.

Prior to testing the vehicle was preconditioned according the CRC Fuel Tank Flushing Procedure and driven to allow the PCM to learn the test fuel. The preconditioning process consisted of a series of three, 13 mile on road drive cycles at speeds from 30 mph to 65 mph. The vehicle was allowed to sit for a minimum of 6 hours between drive cycles.

The low speed testing, sections A-K of the driveability procedure, was conducted in a paved parking lot with dimensions of 240 feet by 780 feet. A parking lot was adequate for this portion of testing due to the 20 mile per hour (mph) maximum test speed achieved during steps A-K. The higher speed testing, sections L-N of the driveability procedure, was conducted on a paved road adjacent to the parking lot. Data was recorded using the CRC Driveability Data Sheet. A copy of the CRC Driveability Data Sheet can be found in Appendix C.

The CRC Driveability Procedure was started by recording necessary test information such as the overnight soak temperature, temperature at time of testing, vehicle mileage, date, and driver. This information was recorded on the CRC Driveability Data Sheet. The vehicle was then started and the engine cranking time recorded. Idle quality was rated during a five second period immediately after start-up, and for a five second period immediately after shifting into “Drive”. After rating the idle quality the vehicle was driven approximately 20 feet to the starting line. At this time a series of maneuvers were performed which consisted of light throttle acceleration, moderate throttle acceleration, and wide open throttle acceleration. All acceleration maneuvers were conducted by rapidly “snapping” the throttle open to the position that achieved a predetermined manifold vacuum. Light throttle maneuvers were performed at a constant throttle opening beginning at 12 inches of manifold vacuum. Moderate throttle maneuvers were performed at a constant throttle opening beginning at 7 inches of manifold vacuum. Steps E-I of the driveability procedure allow 0.1 miles for each step. These steps were then repeated according to the CRC procedure. The total distance traveled for the low speed portion of the procedure (steps A-K) was 1 mile.

The higher speed portion of the test procedure, steps L-N, immediately followed step K of the low speed testing. During this portion of the test a maximum speed of 45 mph was achieved. Steps L-N consisted of a 0-45 mph crowd acceleration, a 25-35 mph detent acceleration, and a 30 second idle period to monitor idle quality while the transmission was in “Drive”. A crowd acceleration is performed using constant intake manifold vacuum. To maintain constant manifold vacuum the throttle opening was continually increased as engine speed increased. The crowd acceleration was performed at the same manifold vacuum prescribed for light throttle acceleration. The detent acceleration was performed by opening the throttle as far as possible without causing the transmission to downshift. The detent maneuver was performed at 5 inches of manifold vacuum.

The malfunctions recorded during testing were, stall, idle roughness, backfire, hesitation, stumble, and surge. A malfunction severity rating was used to determine the level of intensity associated with any particular malfunction. Definitions of the malfunctions and the severity rating system can be found in the CRC Revised Cold-Start and Warm-Up Driveability Procedure located in Appendix B.

Driveability Test Vehicle

The test vehicle was a 1997 Chevrolet Malibu, VIN # 1G1ND52M6VY100077, with a 3.1 liter V-6 engine and automatic transmission. This vehicle had previously been used in the 1998 Ethanol Vehicle Challenge sponsored by the U.S. Department of Energy and General Motors. Significant modifications were made by a group of Minnesota State University, Mankato students to optimize the operation of the vehicle on E85. Prior to any testing, or preconditioning, the vehicle engine was replaced with the original, unmodified engine. The catalytic converter and fuel pump were replaced with new, original equipment parts obtained from a GM dealer. No modifications were made to the vehicle to adapt to the higher than normal oxygen content of the fuel.

Driveability Test Fuels

Three fuels were used for this test. The base fuel was a non-oxygenated, regular unleaded, 87 octane gasoline purchased from a retail BP gas station. Two ethanol blends were prepared using the base fuel; a 10% ethanol / 90% gasoline blend, and a 20% ethanol / 80% gasoline blend. The fuels were splash blended using gravimetric measurement.

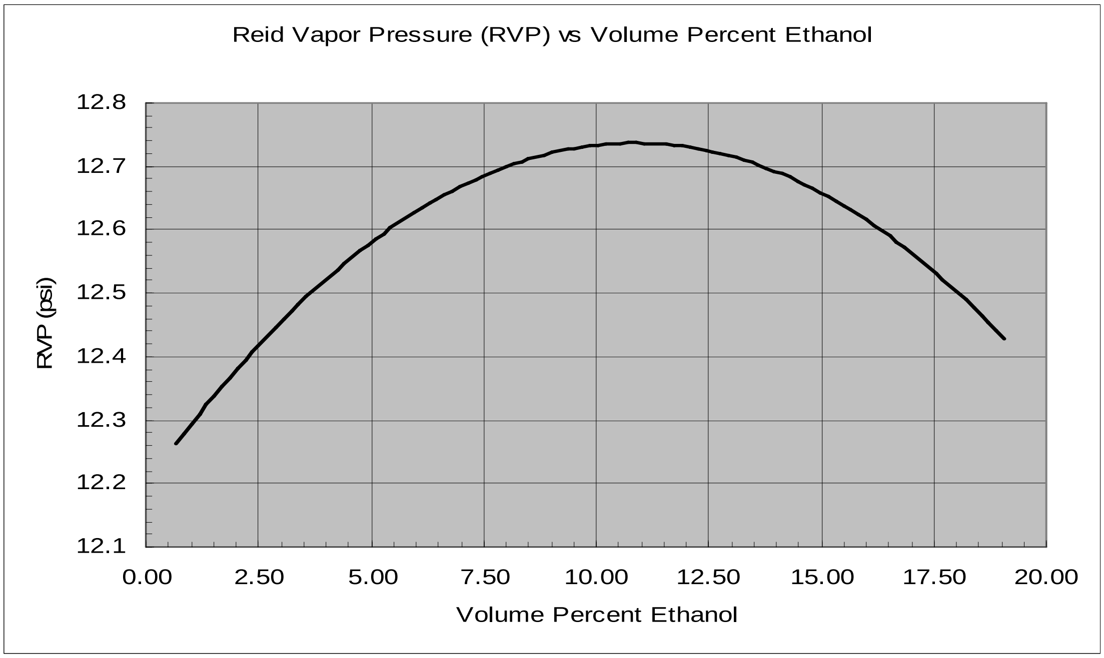
Driveability Fuel Analysis

A fuel analysis was performed by the Minnesota Department of Commerce, Weights and Measures Division. The volume percent ethanol was determined according to ASTM D 4815. The gasoline, as purchased, was determined to contain 0.67% ethanol. The E10 blend contained 10.39% ethanol, and the E20 blend contained 19.05% ethanol. The fuel used for testing was purchased from a retail supplier in Iowa on March 11, 2006. According to ASTM D 4814 (Standard Specification for Automotive Spark-Ignition

Engine Fuel) from September 16 through April 30 volatility properties of the previous month are acceptable for the end user from the 1st through the 15th day of the month. From the 16th day to the end of the month the volatility properties of fuel delivered to the end user shall meet the requirements of the specified class. Gasoline sold in Iowa from March 1- March 15 should have a maximum vapor pressure of 15.0 psi and from March 16 –March 31 the vapor pressure should be a maximum of 13.5 psi (ASTM D 4814). The vapor pressure of the gasoline purchased for testing was analyzed and determined to be 12.26 psi. Although the test fuel was purchased on March 11 it is possible that the gas station had received a delivery of fuel conforming to the requirements for the latter half of the month. The Vapor Pressure of the test fuels are shown in Table 1 and Graph 1.

Table 1: Test Fuel Vapor Pressure

Fuel	**RVP (psi)**
Gasoline	12.26
E10	12.74
E20	12.43



Graph 1

Statistical Methods

After consulting Dr. Mark Zuiker, a professor of applied statistics in the Math and Statistics department at Minnesota State University, Mankato, it was determined that nonparametric statistics should be used due to the small number of tests conducted using each fuel.

For standard parametric statistics to be valid, certain underlying assumptions are made, particularly for smaller sample sizes. A normal distribution of data is assumed when using parametric procedures. If these assumptions are incorrect the resulting P-values and confidence intervals may not be trustworthy. Nonparametric tests make less stringent demands of the data. Nonparametric methods provide for some objectivity when there is no reliable scale for the original data and there is some concern that the results of standard parametric methods would be criticized for their dependence on an assumed distribution. For example, the one-sample “T test” requires that the observations be drawn from a normally distributed population. For two independent samples, the “T test” has the additional requirement that the population standard deviations be equal (Dallal, 2006). Because of the small sample size and lack of information about the underlying distribution, nonparametric procedures were chosen.

The Kruskal-Wallis test is a nonparametric method of testing a hypothesis that several populations have the same continuous distribution versus the alternative that measurements tend to be higher in one or more of the populations. When the Kruskal-Wallace test is statistically significant, it indicates a difference between at least two of the sample medians, but does not indicate pairwise which two are different. If the Kruskal-

Wallace test is significant, then the Mann-Whitney test may be used to make pairwise comparisons (Sheskin, 1997). This test is appropriate when comparing the medians of two independent samples. When the Mann-Whitney test is significant, it indicates that there is a significant difference between the two sample medians (Conover, 1980). The Kruskal-Wallace test and Mann-Whitney test were used to analyze statistical trends in the data from this research.

The Kruskal-Wallace multiple comparison test was performed at the Alpha = 0.05 level. The confidence intervals associated with the Mann-Whitney test were completed at the Alpha = 0.036 level for a 96.4% confidence interval. The level of significance for this test is sample size dependent. A 96.4% confidence interval was the closest approximation to a 95% confidence interval that could be computed for a sample size of five observations. In that it is more precise, this will yield slightly more conservative estimates of the range of plausible values for the differences in the two medians. All results in this research are reported at the approximate 0.05 level of significance (M. Zuiker, personal communication, June 16, 2006).

CHAPTER III

Results

Emission /Fuel Economy Analysis

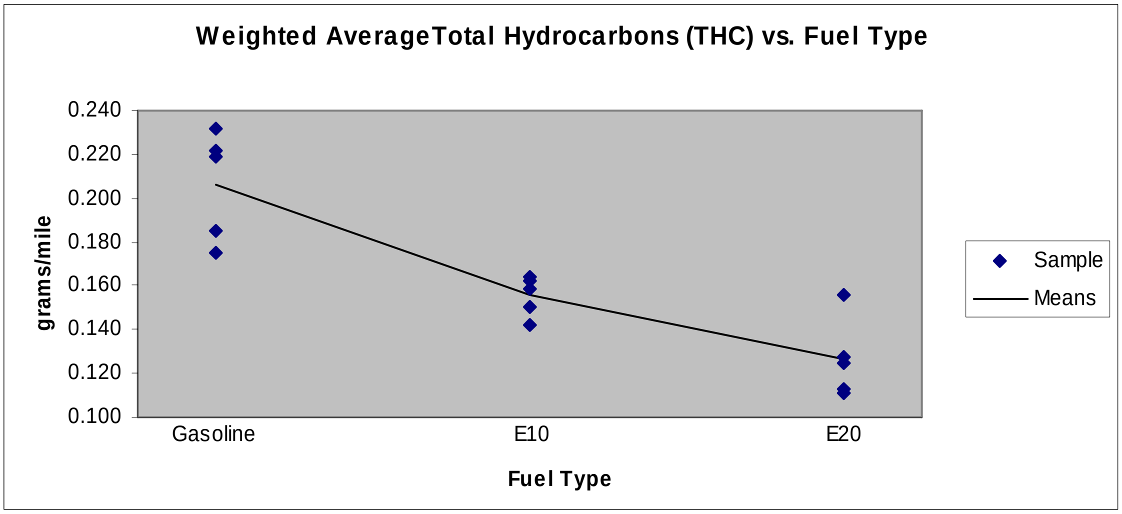
The data from this research has been statistically analyzed to determine if statistically significant trends in the data exist. Emissions data from the Weighted Average and Phase 1 of the EPA 78 test were examined. Data from Phase 1 was analyzed because the catalytic converter is cold, and therefore, not functioning at the beginning of the test. Most of the emissions of THC and CO are generated during this portion of the test. The results from the Weighted Average are the only results used by the EPA to determine the tailpipe emissions from a vehicle. The Weighted Average is calculated using the data obtained from each of the three phases of the EPA 78 test. The formula for calculating the Weighted Average can be found in Appendix D. Fuel economy data from the EPA 78 test and the HWFET was analyzed. Data from these two tests is used to generate the fuel economy numbers advertised on the window sticker of a new vehicle. The city fuel economy is calculated by multiplying the EPA 78 MPG by 0.90, and the highway fuel economy is calculated by multiplying the HWFET MPG by 0.78 according to 40 CFR 600.209-95. The fuel economy results from the drive cycles are multiplied by a factor to decrease the fuel economy numbers and more closely approximate the actual fuel economy obtained under on road driving conditions.

The individual emissions analyses for results from the Weighted Average are presented in Tables 2-5 and Graphs 2-5.

Table 2 contains the Weighted Average THC data from all three fuels for each of the five tests. Graph 2 illustrates a decreasing trend in THC emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate a statistically significant difference in THC emissions does exist between Tier II gasoline and E10, and Tier II gasoline and E20. However, there is no statistically significant difference in THC emissions between E10 and E20. The results of the statistical analysis indicate a reduction in THC emissions for E10 and E20 when compared to Tier II gasoline.

Table 2: Weighted Average Total Hydrocarbon Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	THC	THC	THC
Run 1	0.232	0.150	0.156
Run 2	0.175	0.159	0.125
Run 3	0.219	0.164	0.127
Run 4	0.222	0.162	0.113
Run 5	0.185	0.142	0.111
Average	0.207	0.155	0.126
Std. Dev.	0.025	0.009	0.018

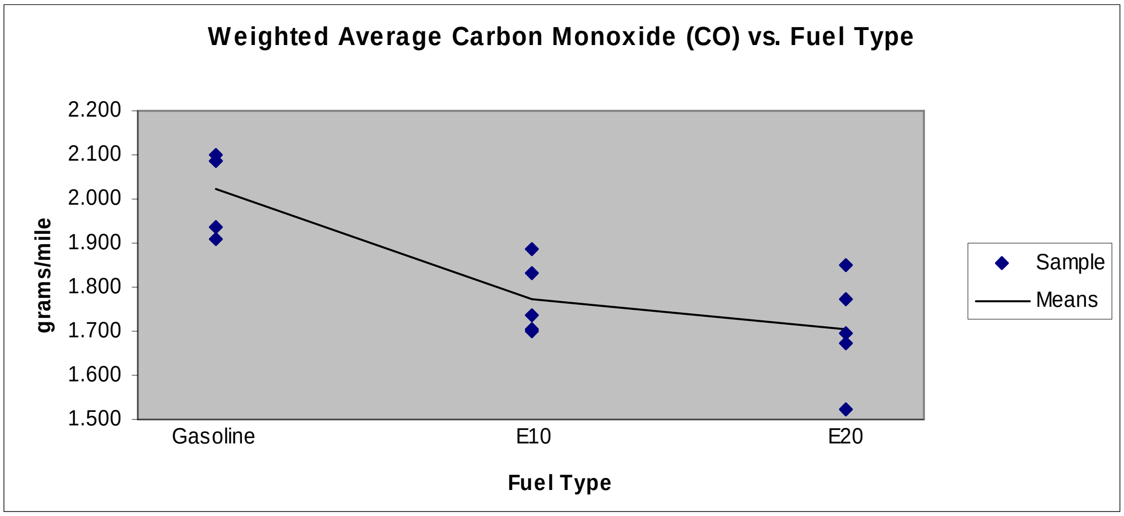


Graph 2

Table 3 contains the Weighted Average CO data from all three fuels for each of the five tests. Graph 3 illustrates a decreasing trend in CO emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate a statistically significant difference in CO emissions does exist between Tier II gasoline and E10, and Tier II gasoline and E20. However, there is no statistically significant difference in CO emissions between E10 and E20. The results of the statistical analysis indicate a reduction in CO emissions for E10 and E20 when compared to Tier II gasoline.

Table 3: Weighted Average Carbon Monoxide Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	CO	CO	CO
Run 1	2.086	1.888	1.673
Run 2	2.087	1.700	1.522
Run 3	2.101	1.737	1.697
Run 4	1.909	1.703	1.848
Run 5	1.938	1.833	1.773
Average	2.024	1.772	1.703
Std. Dev.	0.093	0.084	0.122

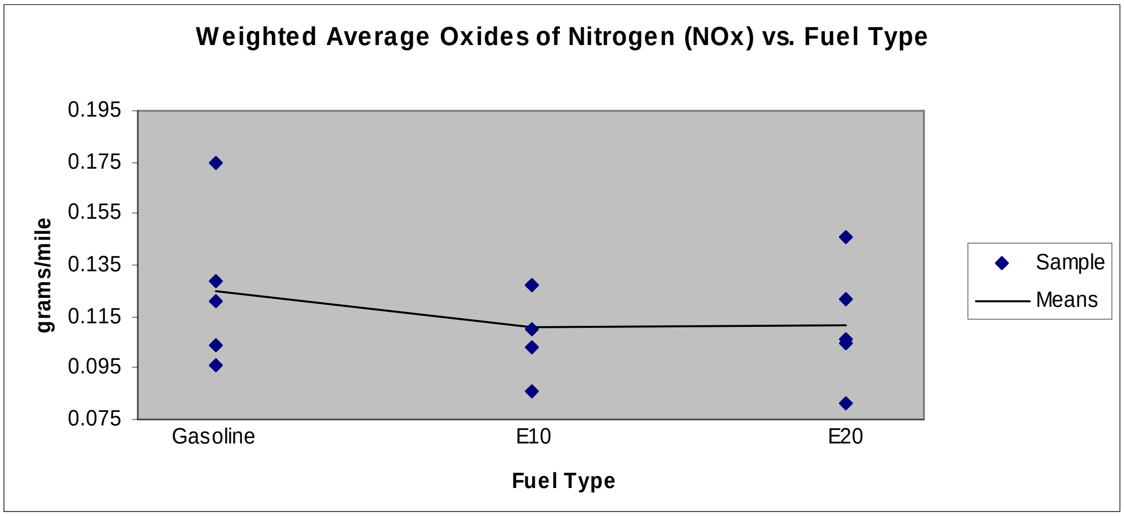


Graph 3

Table 4 contains the Weighted Average NOx data from all three fuels for each of the five tests. Graph 4 illustrates no trend in NOx emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate no statistically significant difference in NOx emissions exist between Tier II gasoline, E10, or E20.

Table 4: Weighted Average Oxides of Nitrogen Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	Nox	Nox	Nox
Run 1	0.121	0.127	0.106
Run 2	0.096	0.086	0.122
Run 3	0.175	0.110	0.105
Run 4	0.129	0.103	0.081
Run 5	0.104	0.127	0.146
Average	0.125	0.111	0.112
Std. Dev.	0.031	0.017	0.024

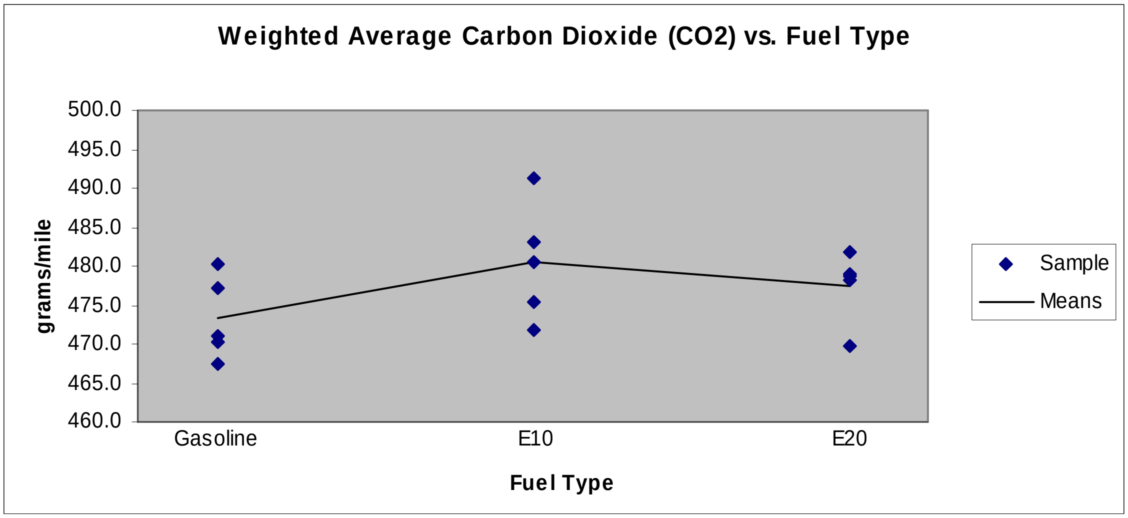


Graph 4

Table 5 contains the Weighted Average CO2 data from all three fuels for each of the five tests. Graph 5 illustrates no trend in CO2 emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate no statistically significant difference in CO2 emissions exist between Tier II gasoline, E10, or E20.

Table 5: Weighted Average Carbon Dioxide Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	CO2	CO2	CO2
Run 1	480.16	491.37	481.74
Run 2	471.13	483.16	478.70
Run 3	470.26	480.60	478.87
Run 4	467.55	471.72	478.31
Run 5	477.08	475.34	469.87
Average	473.24	480.44	477.50
Std. Dev.	5.20	7.57	4.48



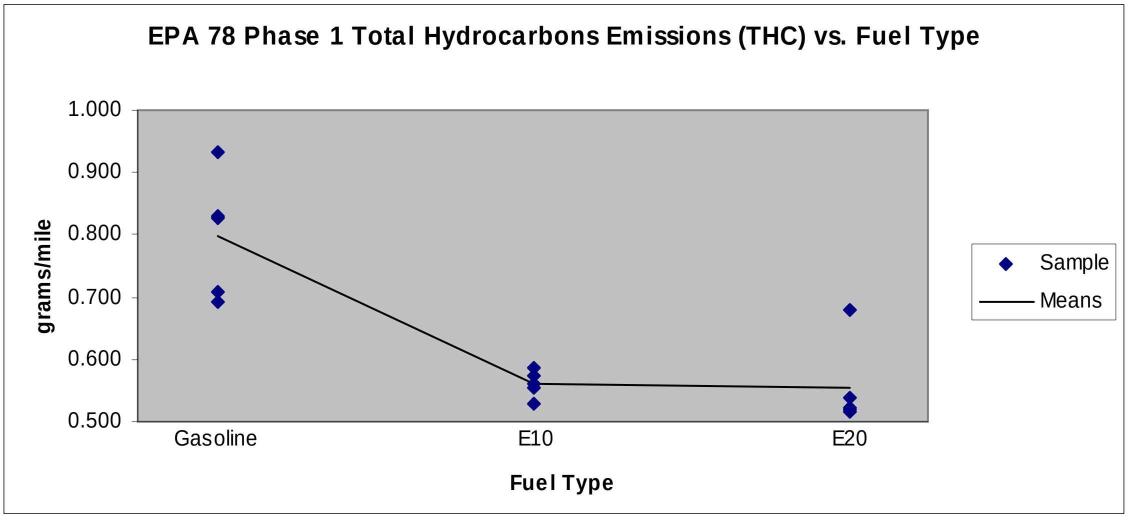
Graph 5

The individual emissions analyses for results from Phase 1 are presented in Tables 6-9 and Graphs 6-9.

Table 6 contains the Phase 1 THC data from all three fuels for each of the five tests. Graph 6 illustrates a decreasing trend in THC emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate a statistically significant difference in THC emissions does exist between Tier II gasoline and E10, and Tier II gasoline and E20. However, there is no statistically significant difference in THC emissions between E10 and E20. The results of the statistical analysis indicate a reduction in THC emissions for E10 and E20 when compared to Tier II gasoline.

Table 6: Phase 1 Total Hydrocarbon Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	THC	THC	THC
Run 1	0.934	0.573	0.679
Run 2	0.709	0.530	0.517
Run 3	0.828	0.554	0.537
Run 4	0.831	0.562	0.519
Run 5	0.692	0.586	0.521
Average	0.799	0.561	0.555
Std. Dev.	0.100	0.021	0.070

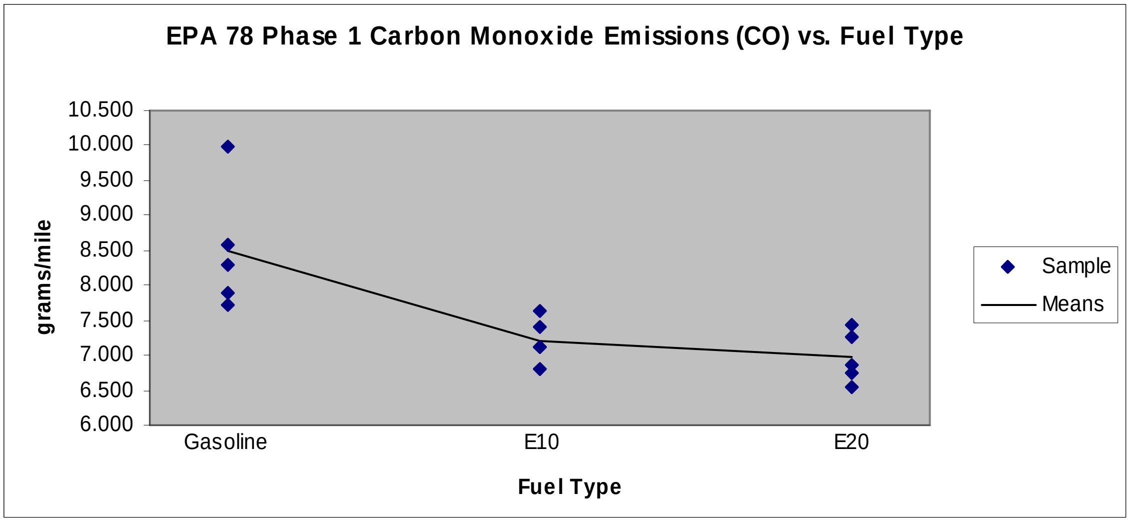


Graph 6

Table 7 contains the Phase 1 CO data from all three fuels for each of the five tests. Graph 7 illustrates a decreasing trend in CO emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate a statistically significant difference in CO emissions does exist between Tier II gasoline and E10, and Tier II gasoline and E20. However, there is no statistically significant difference in CO emissions between E10 and E20. The results of the statistical analysis indicate a reduction in CO emissions for E10 and E20 when compared to Tier II gasoline.

Table 7: Phase 1 Carbon Monoxide Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	CO	CO	CO
Run 1	9.997	7.404	6.746
Run 2	8.577	6.795	6.548
Run 3	8.281	7.107	6.874
Run 4	7.903	7.115	7.434
Run 5	7.719	7.634	7.251
Average	8.495	7.211	6.971
Std. Dev.	0.903	0.320	0.365

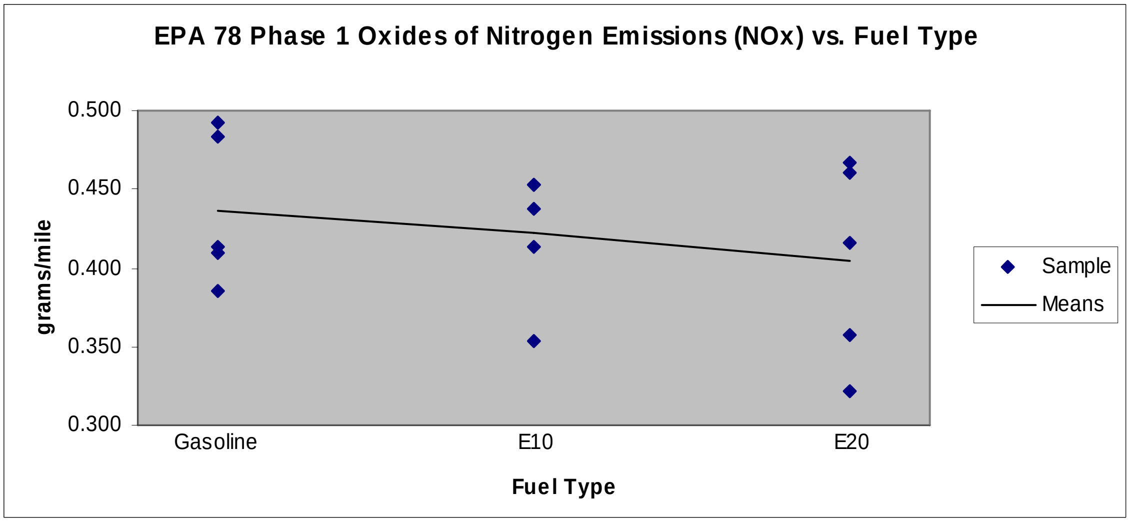


Graph 7

Table 8 contains the Phase 1 NOx data from all three fuels for each of the five tests. Graph 8 illustrates no trend in NOx emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate no statistically significant difference in NOx emissions exist between Tier II gasoline, E10, or E20.

Table 8: Phase 1 Oxides of Nitrogen Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	Nox	Nox	Nox
Run 1	0.385	0.438	0.357
Run 2	0.414	0.413	0.461
Run 3	0.483	0.354	0.416
Run 4	0.492	0.453	0.322
Run 5	0.409	0.453	0.467
Average	0.437	0.422	0.405
Std. Dev.	0.048	0.041	0.064

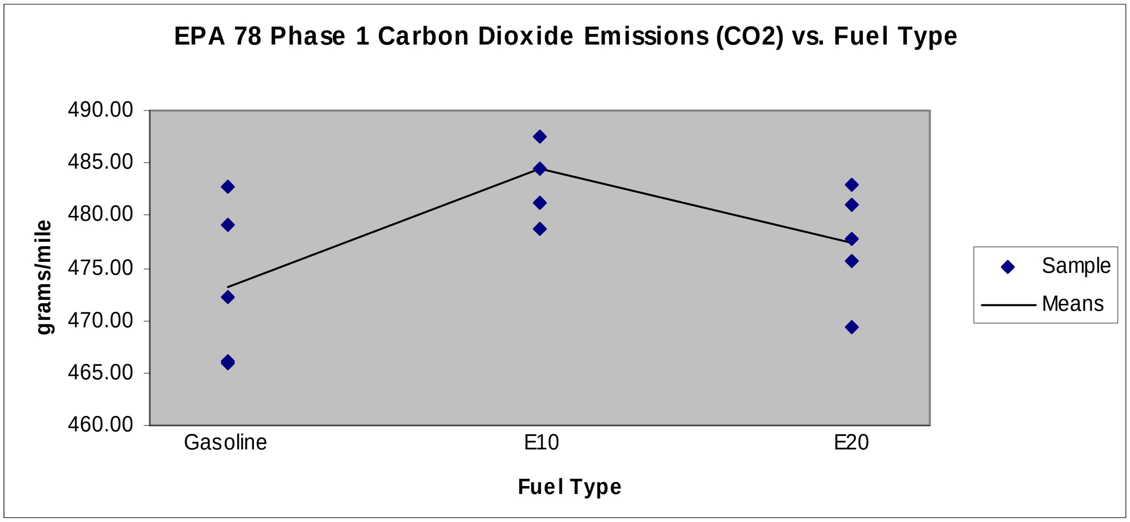


Graph 8

Table 9 contains the Phase 1 CO2 data from all three fuels for each of the five tests. Graph 9 illustrates no trend in CO2 emissions as ethanol content increased from 0-20%. The results of the statistical analysis indicate no statistically significant difference in CO2 emissions exist between Tier II gasoline, E10, or E20.

Table 9: Phase 1 Carbon Dioxide Data

Fuel	**Gasoline**	**E10**	**E20**
grams/mile	CO2	CO2	CO2
Run 1	482.73	490.24	482.89
Run 2	479.20	481.26	477.84
Run 3	466.17	487.60	481.02
Run 4	466.01	478.67	475.66
Run 5	472.18	484.49	469.36
Average	473.26	484.45	477.35
Std. Dev.	7.57	4.66	5.27



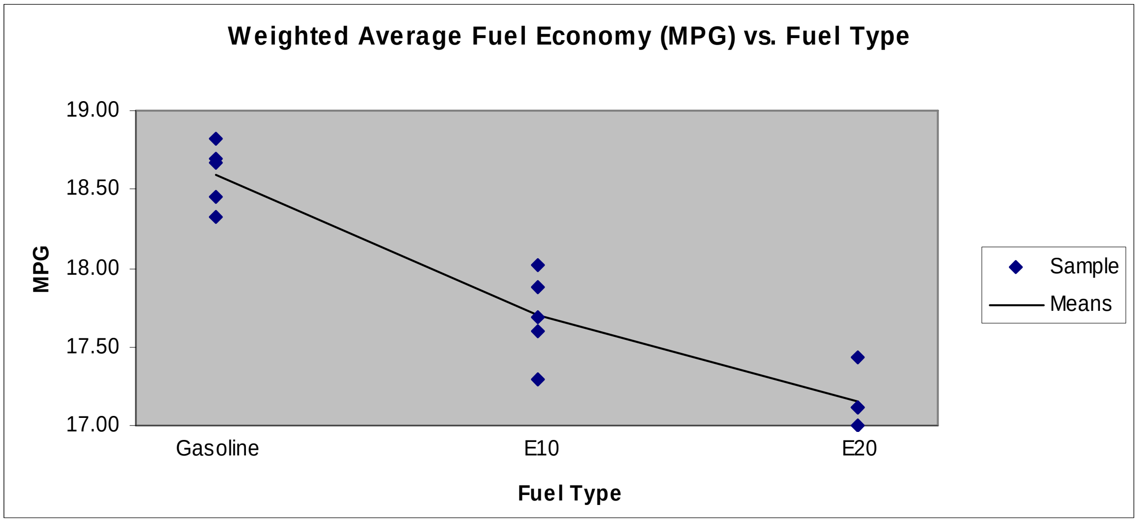
Graph 9

The fuel economy analysis for results from the EPA 78 Weighted Average and the HWFET are presented in Tables 10-12 and Graphs 10-12.

Table 10 contains the EPA 78 Weighted Average fuel economy data from all three fuels for each of the five tests. Graph 10 illustrates a decreasing trend in fuel economy as ethanol content increased from 0-20%. The results of the statistical analysis indicate a statistically significant difference in fuel economy does exist between Tier II gasoline and E10, and Tier II gasoline and E20. However, there is no statistically significant difference in fuel economy between E10 and E20. The results of the statistical analysis indicate a reduction in fuel economy for E10 and E20 when compared to Tier II gasoline.

Table 10: EPA 78 Weighted Average Fuel Economy Data

Fuel	**Gasoline**	**E10**	**E20**
Fuel economy	MPG	MPG	MPG
Run 1	18.32	17.29	17.00
Run 2	18.67	17.60	17.12
Run 3	18.70	17.69	17.11
Run 4	18.82	18.02	17.12
Run 5	18.45	17.88	17.43
Average	18.59	17.70	17.16
Std. Dev.	0.20	0.28	0.16

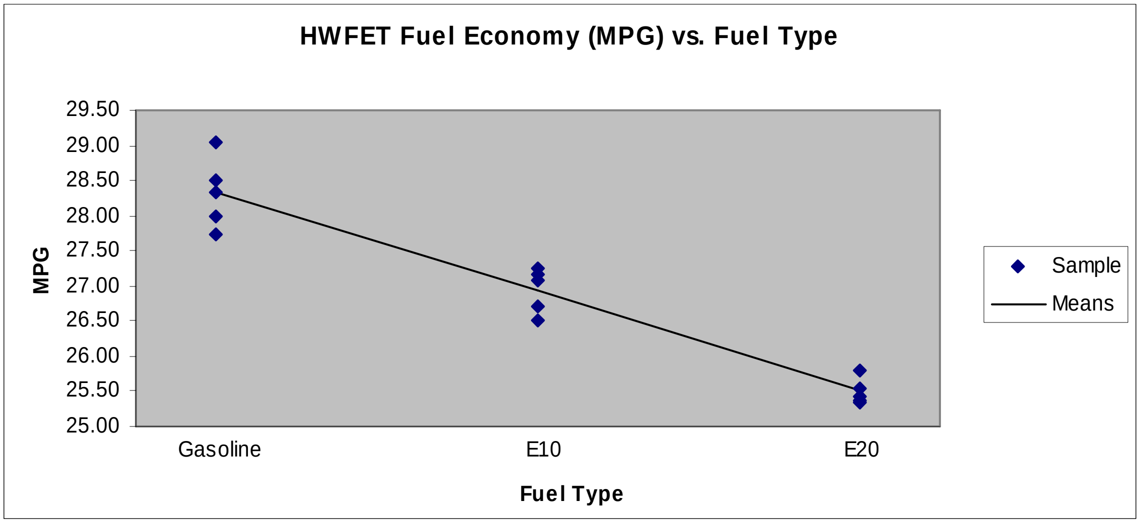


Graph 10

Table 11 contains the HWFET fuel economy data from all three fuels for each of the five tests. Graph 11 illustrates a decreasing trend in fuel economy as ethanol content increased from 0-20%. The results of the statistical analysis indicate a statistically significant difference in fuel economy does exist between Tier II gasoline and E10, Tier II gasoline and E20, and between E10 and E20. The results of the statistical analysis indicate a decreasing trend in highway fuel economy as ethanol content increased from 0-20%.

Table 11: HWFET Fuel Economy Data

Fuel	**Gasoline**	**E10**	**E20**
Fuel economy	MPG	MPG	MPG
Run 1	28.00	26.50	25.38
Run 2	28.33	27.25	25.53
Run 3	28.51	26.72	25.44
Run 4	29.04	27.17	25.35
Run 5	27.73	27.09	25.80
Average	28.32	26.95	25.50
Std. Dev.	0.50	0.32	0.18

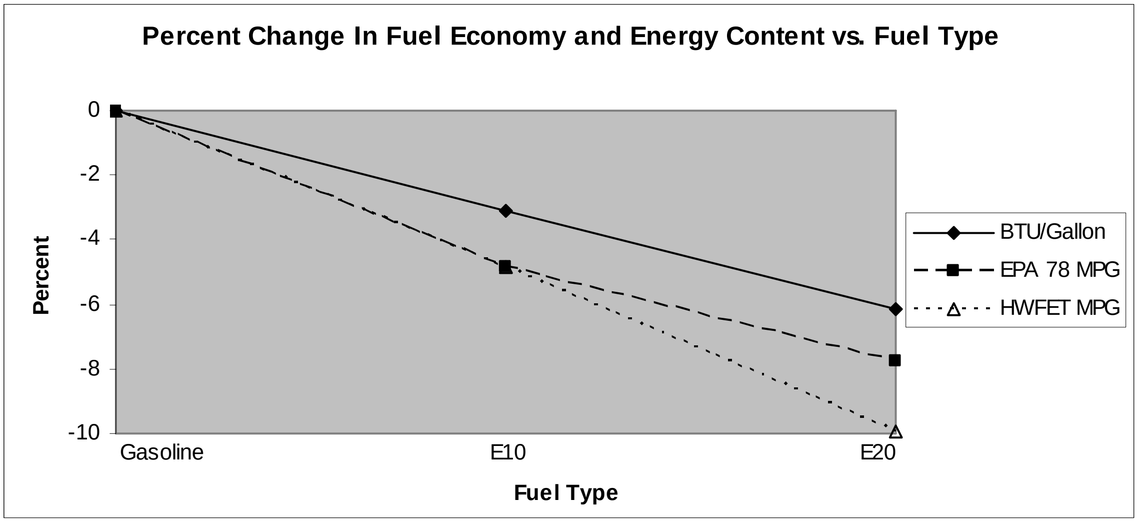


Graph 11

Table 12 contains the percent change in fuel economy and energy content for E10 and E20 compared to gasoline. Graph 12 illustrates a decreasing trend in energy content and fuel economy as ethanol content was increased from 0-20%

Table 12: Percent change in Fuel Economy and Energy Content

Fuel Type	BTU/Gallon	Average EPA 78 MPG	Average HWFET MPG
Gasoline	0	0	0
E10	-3.09	-4.84	-4.84
E20	-6.14	-7.76	-9.96



Graph 12

Driveability Results

The data was collected using the CRC Driveability Data Sheet. The total weighted demerit (TWD) system used in the CRC procedure was not used due to the low number of driveability problems experienced during testing. It was expected that the vehicle would experience the most driveability problems during the "Worst Case Scenario" test using E20. This assumption was based on the fact that the engine would experience a lean fuel condition due to the extra oxygen contained in the E20 fuel. For this test the vehicle PCM was not allowed to learn the E20 fuel. Prior to this test the vehicle had been preconditioned on gasoline, defueled, and then refueled with E20. The car performed as well during this test as in any other test. From the data obtained during driveability testing it is not possible to determine if one fuel contributes more to driveability problems than the other fuels.

CHAPTER IV

Discussion

This research was initiated with the intent of determining to what extent the addition of ethanol to gasoline would affect the exhaust emissions, fuel economy, and driveability of a 1997 Chevrolet Malibu. The findings of this research indicated that the addition of ethanol to gasoline did affect the emissions and fuel economy of the test vehicle but did not affect the driveability. These results suggest that a significant difference in exhaust emissions and fuel economy exists between gasoline and E10, and between gasoline and E20, but no significant difference exists between E10 and E20.

Overall THC emissions decreased by 25% when using E10 and by 39% when using E20. CO emissions decreased by 12% when using E10 and by 16% when using E20. NOx emissions and CO2 emissions did not change. City fuel economy decreased by 5% when using E10 and by 8% when using E20. Highway fuel economy decreased by 5% when using E10 and by 10% when using E20. The reason for a greater reduction in fuel economy when compared to the energy content of the fuel is difficult to explain. It may be due to engine design, fuel system design, or the engine control system.

Limitations to This Study

Several limitations have been identified in this research. The use of only one vehicle for driveability testing was a major limitation to that portion of this research. As discussed earlier, the test equipment in this research was different from equipment specified in the Code of Federal Regulations for conducting certification emission testing. However, the correlation of the equipment used to that of certification equipment is very good. Another limitation of this research was the small sample size. This was due to the limited amount of time and additional cost of conducting more tests. Because a small sample size reduces power, the likelihood of obtaining statistical significance decreases. The use of a late model, fuel injected, computer controlled vehicle was also a limiting factor in that the findings in this research cannot be applied to older model carbureted vehicles.

Recommendations for Future Research

Future research could focus on some of the limitations to the present research. First of all, additional tests could be performed to increase the sample size and increase the likelihood of obtaining statistically significant results. To address issues related to equipment, it would be interesting to conduct a similar study and perform additional tests at a federally certified emission testing laboratory and compare the data with data obtained from the MnCAR lab. It is also recommended that several vehicles be used to determine the effect on driveability.

Conclusion

Previous research on gasoline / ethanol blends containing more than 10% volume ethanol indicated the possibility for current vehicles used today to operate effectively on a 20% ethanol / 80% gasoline blend. THC and CO emissions would most likely be lower and NOx emissions would likely be higher. CO2 emissions would likely stay about the same. Fuel economy would likely decrease in proportion to the energy content of the fuel. Some vehicles would experience driveability problems due to their inability to deal with the increased oxygen content of the fuel. The issues associated with material compatibility must be examined more closely to determine the durability of vehicles over the long term use of E20.

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Appendix A

CRC Fuel Tank Flushing Procedure

Precautionary notes:

1. When draining the vehicle fuel tank, leave the fuel pump on until no drops are coming out of the line. This will ensure that each vehicle fuel tank drain is complete, and the same as the other fuel tank drains.

2. Use a UL approved ground strap to ground defueling equipment to the fuel injector rail or fuel line fitting for all fuel draining.

Flushing Procedure:

1. When a vehicle comes in from testing, hook up the chilled sampling system, and draw the required fuel sample through the Schrader valve or adapter line fitting using the vehicle fuel pump.

2. Remove the sampling system. Immediately prior to testing, install drain line, and then completely drain the fuel tank through the Schrader valve or adapter line fitting using the vehicle fuel pump.

3. Remove the fill cap, add four gallons of the next test fuel to the vehicle fuel tank, and replace the fill cap.

4. Start and idle the vehicle for a total of 2 minutes.

5. Completely drain the fuel tank through the Schrader valve or adapter line fitting using the vehicle fuel pump.

6. Remove the fill cap, add four gallons of the next test fuel to the vehicle fuel tank, and replace the fill cap.

7. Start and idle the vehicle for a total of 2 minutes. From approximately 15 seconds into the idle for a period of 30 seconds, rock the rear end of the vehicle from side to side. This task will require one person on each side of the vehicle.

8. Completely drain the fuel tank through the Schrader valve or adaptive line fitting using the vehicle fuel pump.

9. When the rating crew is ready, remove the fill cap, add four or five gallons as required of the test fuel to the vehicle fuel tank, and replace the fill cap.

Appendix B

REVISED CRC COLD-START AND WARMUP DRIVEABILITY PROCEDURE

A. Record all necessary test information at the top of the data sheet.

B. Turn key on for 2 seconds before cranking to pressurize fuel system. Make sure defrost is on and fan is in "low" position. Start engine per Owner's Manual Procedure. Record start time.

C. There may be a total of three starting attempts recorded. If the engine fails to start within 5 seconds on any of these attempts, stop cranking at 5 seconds and record "NS" (no start) in the appropriate starting time box on the data sheet. After the first and second unsuccessful attempts to start, turn the key to the "off" position before attempting to restart per the Owners Manual procedure. If the engine fails to start after 5 seconds during the third attempt, record an "NS" in the Restart2 box, then start the engine any way possible and proceed as quickly as possible to Step D without recording any further start times.
Once the engine starts on any of the first three attempts, idle in park for 5 seconds and record the idle quality. If the engine stalls during this 5-second idle, record a stall in the Idle Park "Stls" box, then restart per the above paragraph, subject to a combined maximum (in any order) of three no-starts and Idle Park stalls. After all the start-time boxes are filled, no further starts should be recorded.

D. Apply brakes (right foot), shift to "Drive" ("Overdrive" if available) for 5-second idle, and record idle quality. If engine stalls, restart immediately. Do not record restart time. Record number of stalls. A maximum of three Idle Drive stalls may be recorded; however, only one stall contributes to demerits. If the engine stalls a fourth time, restart and proceed to the next maneuver as quickly as possible. It is important to complete the start-up procedure as quickly as possible to prevent undue warm-up before the driving maneuvers and to maintain vehicle spacing on the test track.

E. After idling 5 seconds (Step D), make a brief 0-15 mph light-throttle acceleration. Light-throttle accelerations will be made at a constant throttle opening beginning at a predetermined manifold vacuum. This and all subsequent accelerations throughout the procedure should be "snap" maneuvers: the throttle should be depressed immediately to the position that achieves the pre-set manifold vacuum, rather than easing into the acceleration. Once the throttle is depressed, no adjustment should be made, even if the pre-set vacuum is not achieved. Use moderate braking to stop. Idle for approximately 3 seconds without rating it. Make a brief 0-15 mph light-throttle acceleration. Both accelerations together should be made within 0.1-mile. If both accelerations are completed before the 0.1-mile marker, cruise at 15 mph to the 0.1-mile marker. Use moderate braking to stop; idle for approximately 3 seconds without rating it.

F. Make a 0-20 mph wide-open-throttle (WOT) acceleration beginning at the 0.1 mile marker. Use moderate braking to achieve 10 mph and hold 10 mph until the 0.2-mile marker (approximately 5 seconds). Use moderate braking to stop; idle for approximately 3 seconds without rating it.

G. At the 0.2-mile marker, make a brief 0-15 mph light-throttle acceleration. Use moderate braking to stop. Idle for approximately 3 seconds without rating it. Make a brief 0-15 mph light-throttle acceleration. If accelerations are completed before the 0.3 mile marker, cruise at 10 mph to the 0.3 mile marker.

H. At the 0.3 mile marker, make a light-throttle acceleration from 10-20 mph. Use moderate braking to make a complete stop at the 0.4 mile marker in anticipation of the next maneuver. Idle for approximately 3 seconds at the 0.4 mile marker without rating the idle.

I. Make a 0-20 mph moderate acceleration beginning at the 0.4 mile marker.

J. At the 0.5-mile marker, brake moderately and pull to the right side of the roadway. Idle in "Drive" for 5 seconds and record idle quality. Slowly make a U-turn.

K. Repeat Steps E through J. At the 0.0-mile marker, brake moderately and slowly make a U-turn.

NOTE: Items L-N may be useful only at colder temperatures.

L. Make a crowd acceleration (constant predetermined vacuum) from 0-45 mph. Four-tenths of a mile is provided for this maneuver. Decelerate from 45 to 25 mph before the 0.4 mile marker. At the 0.4 mile marker, make a 25-35 mph detent position acceleration.

N. At the 0.5-mile marker, brake moderately. Idle for 30 seconds in "Drive," recording idle quality after 5 seconds and after 30 seconds, and record any stalls that occur. This ends the driving schedule. Proceed to the staging area. Definitions of light-throttle, detent, and WOT accelerations are attached. During the above maneuvers, observe and record the severity of any of the following malfunctions (see attached definitions).

It is possible that during a maneuver, more than one malfunction may occur. Record all deficiencies observed. Do not record the number of occurrences. If no malfunctions occur during a maneuver, draw a horizontal line through all boxes for that maneuver. Also, in recording subjective ratings (T, M, or H), be sure the entry is legible. At times, M and H recordings cannot be distinguished from each other.

Record maneuvering stalls on the data sheet in the appropriate column: accelerating or decelerating. If the vehicle should stall before completing the maneuver, record the stall and restart the car as quickly as possible. Bring the vehicle up to the intended final speed of the maneuver. Any additional stalls observed will not add to the demerit total for the maneuver, and it is important to maintain the driving schedule as closely as possible.

DEFINITIONS AND EXPLANATIONS

Test Run

Operation of a car throughout the prescribed sequence of operating conditions and/or maneuvers for a single test fuel.

Maneuver

A specified single vehicle operation or change of operating conditions (such as idle, acceleration, or cruise) that constitutes one segment of the driveability driving schedule.

Cruise

Operation at a prescribed constant vehicle speed with a fixed throttle position on a level road.

Wide Open Throttle (WOT) Acceleration

"Floorboard" acceleration through the gears from prescribed starting speed. Rate at which throttle is depressed is to be as fast as possible without producing tire squeal or appreciable slippage.

Part-"Throttle (PT) Acceleration

An acceleration made at any defined throttle position, or consistent change in throttle position, less than WOT. Several PT accelerations are used. They are:

1. Light Throttle (Lt. Th) - All light-throttle accelerations are begun by opening the throttle to an initial manifold vacuum and maintaining constant throttle position throughout the remainder of the acceleration. The vacuum selected is the vacuum setting necessary to reach 25 mph in 9 seconds. The vacuum setting should be determined when the vehicle is cold. The vacuum setting is posted in each vehicle.

2. Moderate Throttle (Md. Th) - Moderate-throttle accelerations are begun by immediately depressing the throttle to the position that gives the pre-specified vacuum and maintaining a constant throttle position throughout the acceleration. The moderate-throttle vacuum setting is determined by taking the mean of the vacuum observed during WOT acceleration and the vacuum prescribed for light-throttle acceleration. This setting is to be posted in the vehicle.

3. Crowd - An acceleration made at a constant intake manifold vacuum. To maintain constant vacuum, the throttle-opening must be continually increased with increasing engine speed. Crowd accelerations are performed at the same vacuum prescribed for the light-throttle acceleration.

4. Detent - All detent accelerations are begun by opening the throttle to just above the downshift position as indicated by transmission shift characteristic curves. Manifold vacuum corresponding to this point at 25 mph is posted in each vehicle. Constant throttle position is maintained to 35 mph in this maneuver.

Malfunctions

1. Stall

   Any occasion during a test when the engine stops with the ignition on. Three types of stall, indicated by location on the data sheet, are:

   a. Stall, idle - Any stall experienced when the vehicle is not in motion, or when a maneuver is not being attempted.

   b. Stall, maneuvering - Any stall which occurs during a prescribed maneuver or attempt to maneuver.

   c. Stall: decelerating - Any stall which occurs while decelerating between maneuvers.

2. Idle Roughness

   An evaluation of the idle quality or degree of smoothness while the engine is idling. Idle quality may be rated using any means available to the lay customer. The rating should be determined by the worst idle quality experienced during the idle period.

3. Backfire

   An explosion in the induction or exhaust system.

4. Hesitation

   A temporary lack of vehicle response to opening of the throttle.

5. Stumble

   A short, sharp reduction in acceleration after the vehicle is in motion.

6. Surge

   Cyclic power fluctuations.

Malfunction Severity Ratings

The number of stalls encountered during any maneuver are to be listed in the appropriate data sheet column. Each of the other malfunctions must be rated by severity and the letter designation entered on the data sheet. The following definitions of severity are to be applied in making such ratings.

1. Trace (T) - A level of malfunction severity that is just discernible to a test driver but not to most laymen.

2. Moderate (M) - A level of malfunction severity that is probably noticeable to the average laymen.

3. Heavy (H) - A level of malfunction severity that is pronounced and obvious to both test driver and layman.

4. Extreme (E) - A level of malfunction severity more severe than "Heavy" at which the lay driver would not have continued the maneuver, but taken some other action.

Enter a T, M, H, or E in the appropriate data block to indicate both the occurrence of the malfunction and its severity. More than one type of malfunction may be recorded on each line. If no malfunctions occur, enter a dash (-) to indicate that the maneuver was performed and operation was satisfactory during the maneuver.

DEMERIT CALCULATION SYSTEM

A numerical value for driveability during the CRC test is obtained by assigning demerits to operating malfunctions as shown. Depending upon the type of malfunction, demerits are assigned in various ways. Demerits for poor starting are obtained by subtracting one second from the measured starting time and multiplying by 4. The number of stalls which occur during idle as well as during driving maneuvers are counted separately and assigned demerits as shown. The multiplying x factors of 8 and 32 for idle and maneuvering stalls, respectively, account for the fact that stalls are very undesirable, especially during car maneuvers. A maximum of three total Idle Park stalls and No-Starts are permitted. A maximum of three Idle Drive stalls are permitted.

Other malfunctions, such as hesitation, stumble, surge, idle roughness, and backfire, are rated subjectively by the driver on a scale of trace, moderate, or heavy. For these malfunctions, a certain number of demerits is assigned to each of the subjective ratings. However, since all malfunctions are not of equal importance, the demerits are multiplied by the weighting factors shown to yield weighted demerits.

Finally, weighted demerits, demerits for stalls, and demerits for poor starting are summed to obtain total weighted demerits (TWD), which are used as an indication of driveability during the test. As driveability deteriorates, TWD increases.

A restriction is applied in the totaling of demerits to insure that a stall results in the highest possible number of demerits within a given maneuver. When more than one malfunction occurs during a maneuver, demerits are counted for only the malfunction which had the largest number of weighted demerits. Another restriction is that for each idle period, no more than 3 idle stalls are counted.

When all the factors are multiplied together the following chart of demerit levels is generated.

Demerit levels for: Hesitation/Stumble/Surge/Backfire/Stall

Maneuver	Stall	Extreme	Heavy	Medium	Trace	Clear
Light Throttle	50	16	8	4	2	0
Medium Throttle	100	32	16	8	4	0
WOT	100	32	16	8	4	0
Detent	50	16	8	4	2	0
Crowd	50	16	8	4	2	0

Demerit Levels for Idle Roughness

Extreme	Heavy	Medium	Trace	Clear
8	4	2	1	0

Demerit Levels for Idle Stalls

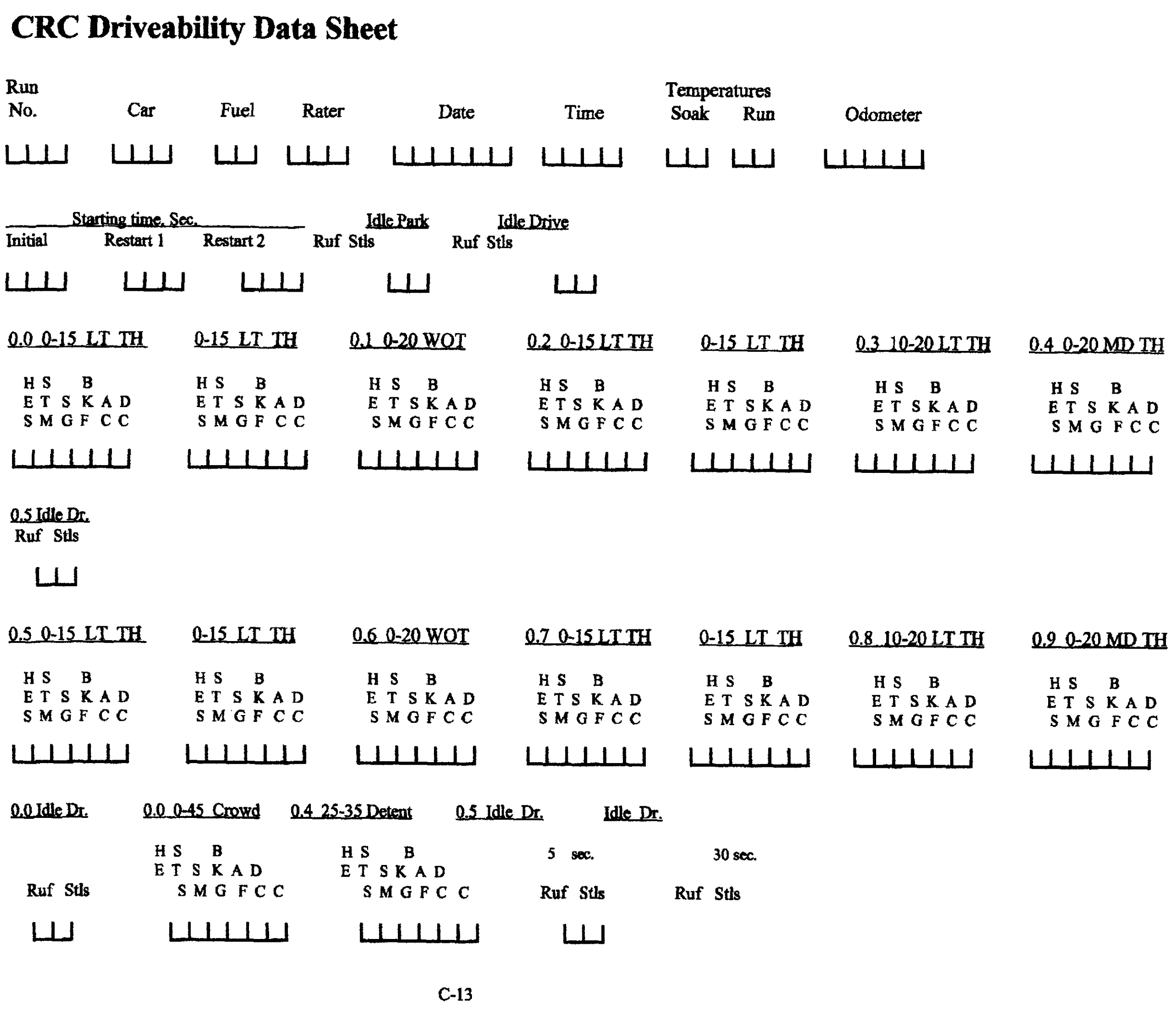
Idle in Park	Starting in Drive	Other Idle (after moderate throttle / end of test)
7 each	28	7

Demerit Levels for Starting

No Start	Slow Start
25 each	t-1*5

The start time, t, is in seconds. Only the results (start, start + stall, no start) of the first three starting attempts in park count toward demerits. Only the first stall in drive prior to maneuvering counts toward demerits. Only the first stall in each maneuver, or in each idle subsequent to the start of the maneuver is counted toward demerits. Only the highest weighted demerit score from each maneuver is counted.

Appendix C



CRC Driveability Data Sheet

Run No.	Car	Fuel	Rater	Date	Time	Temperatures Soak	Temperatures Run	Odometer

Starting time, Sec.			Idle Park	Idle Drive
Initial	Restart 1	Restart 2	Ruf Stls	Ruf Stls

0.0 0-15 LT TH	0-15 LT TH	0.1 0-20 WOT	0.2 0-15 LT TH	0-15 LT TH	0.3 10-20 LT TH	0.4 0-20 MD TH
H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C

0.5 Idle Dr.
Ruf Stls

0.5 0-15 LT TH	0-15 LT TH	0.6 0-20 WOT	0.7 0-15 LT TH	0-15 LT TH	0.8 10-20 LT TH	0.9 0-20 MD TH
H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C

0.0 Idle Dr.	0.0 0-45 Crowd	0.4 25-35 Detent	0.5 Idle Dr.	Idle Dr.
			5 sec.	30 sec.
Ruf Stls	H S B E T S K A D S M G F C C	H S B E T S K A D S M G F C C	Ruf Stls	Ruf Stls

Appendix D

Weighted Average Formula

[.43(Phase 1 distance)(Phase 1 emissions)+(Phase 2 distance)(Phase 2 emissions) +.57(Phase 3 distance)(Phase 3 emissions)] / [.43(Phase 1 distance)+(Phase 2 distance) +.57(Phase 3 distance)]