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E85 1999 CHEVROLET SILVERADO: A Conversion by Minnesota State University, Mankato for the “1999 Ethanol Vehicle Challenge”

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ABSTRACT

A student team from Minnesota State University’s Automotive Engineering Technology program entered the 1999 Ethanol Vehicle Challenge. A 1999 Chevrolet Silverado was converted to run on E85 (85% ethanol, 15% gasoline). The competition consisted of emission, fuel economy, cold-start, and performance evaluations.

The vehicle conversion involved all engine systems, with special emphasis placed on cold-starting, driveability and performance. Laboratory testing led to the final design. The result was an integrated vehicle which successfully ran on E85, but whose use of the alternative fuel was totally transparent to the customer. This paper details the conversion and test results.

Figure 1. MSU’s 1999 Chevrolet Silverado

INTRODUCTION

The 1999 Ethanol Vehicle Challenge was a vehicle design competition for college engineering and engineering technology students. The goal of the competition was to convert a 1999 Chevrolet Silverado (Fig.1) into a vehicle fueled solely by E85 (a blend of 85% denatured ethanol and 15% gasoline). The competition emphasis was to produce a vehicle that had improved fuel economy, low exhaust emissions, and excellent cold-startability, without sacrificing driveability and performance. Fourteen North American colleges and universities were selected to be included in the competition. Selection was based on involvement in the competition in 1998 with the Chevrolet Malibu. Minnesota State University was one of the schools selected. The competition was held May 19 – 26, 1999, at the General Motors Proving Grounds in Milford, Michigan, and concluded with a three day fuel economy road trip to Springfield, IL. The 1999 Ethanol Vehicle Challenge headline sponsors were the U.S. Department of Energy, General Motors Corporation, and National Resources Canada, with support from additional public and private sector entities.

Minnesota State University, Mankato (MSU) is located in southern Minnesota and is one of seven state universities in the Minnesota State Colleges and Universities System (MnSCU). Approximately 13,000 students attend the comprehensive university. Automotive Engineering Technology (AET) is a four-year, Bachelor of Science program located within the College of Science, Engineering and Technology. The program is accredited by the Technology Accreditation Commission of the Accreditation Board for Engineering and Technology (TAC-ABET). As of 1999, the program had 144 majors and a 1998-99 graduating class of 33. Minnesota State’s student branch of the Society of Automotive Engineers has 47 members.

Each student in the program is required to complete a comprehensive senior design project. A group of 9 students chose the 1999 Ethanol Vehicle Challenge as their capstone experience. Work on the project started in the fall of 1998, when the process of planning, design, prototyping, testing and converting the 1999 Chevrolet Silverado to run on E85 began.

CONVERSION

The vehicle selected for use in the 1999 Ethanol Vehicle Challenge was the 1999 Chevrolet Silverado with the optional 5.3 L V-8 engine, automatic transmission, and automatic four-wheel drive. Each of the 14 collegiate teams in the competition received identical vehicles in September, 1998. The Silverados were provided to each of the schools by General Motors. Using the comprehensive rules which had been established for the competition, MSU's student team began the modification of the vehicle using a systems approach. The competition rules and scoring structure served as the criteria against which all decisions on modifications were made. If a modification did not produce lower emissions, higher fuel economy, increased acceleration, improved handling, or better cold start/driveability, it was not used. If a trade-off situation was encountered, where a modification created a gain in one criterion but a loss in another, the relative effect on event scoring was evaluated to determine the better choice. The systems approach involved the engine's fuel system, mechanical system, ignition system, cooling system, lubrication system, and emission system. Powertrain Control Module (PCM) cold-start/driveability, power boosting, and body/chassis modifications were viewed as four additional design areas.

FUEL SYSTEM – The first concern in the fuel system was how to increase fuel flow. With the use of E85, the energy density dropped from gasoline's 31,500 kJ/L to 22,650 kJ/L. To produce power levels equal to those produced on gasoline, volumetric fuel flow needed to be increased to provide an equal amount of energy into the engine's combustion chamber. Theoretically, 39.1% more flow was required, but with ethanol's more efficient burning and modifications used to optimize the engine for the ethanol (such as higher compression ratio) past research at MSU (SAE952749) had shown that approximately 25% more fuel flow was required. A second area of concern was ethanol's compatibility with all materials with which it came into contact. All components needed to be compatible with ethanol. The final concern involved the fuel tank vapors igniteability when the tank was near empty or when refueling was in progress. The possible static electricity caused by the fuel flow could create a spark, which could lead to ignition of the vapors. With these issues identified, choices on the fuel system design were made and the system modified accordingly. All components not detailed were determined to be E85 compatible and not modified.

Fuel Pump – General Motors provided each team with a fuel pump (Fig. 2). This pump (AC P/N 15038363ABC) was rated at 29-g/sec at 425-kPa flow and were made of ethanol compatible material. The pump provided enough E85 flow for all conditions except wide-open throttle at engine speeds over 3000 rpm. At that point, with extra airflow being provided by the supercharger, additional fuel flow was needed. A "Boost-A-Pump" from Whipple Industries was used. This device increased the voltage to the fuel pump from 14 volts to 18 volts during times of wide-open throttle operation. This increased voltage, for short periods of time, increased maximum fuel flow. The device was a solid state voltage controller, which was signaled by the supercharger's microprocessor. Input signals of throttle position and RPM were used.

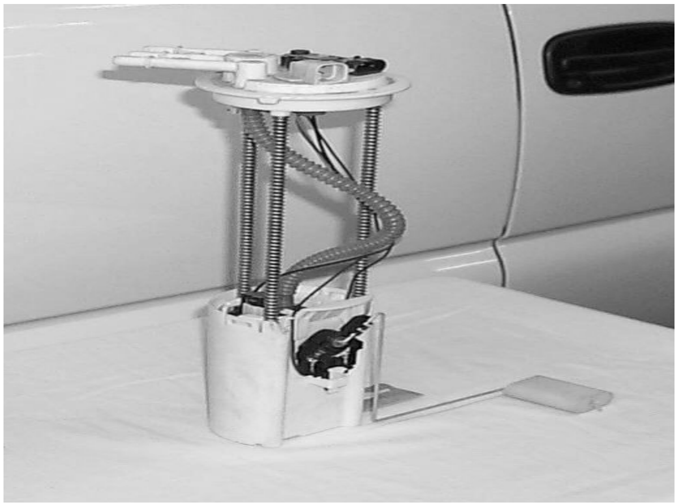

Figure 2. Fuel Pump

Fuel Injectors – Ethanol compatible fuel injectors (Delphi P/N 25324455BA) were provided by General Motors (Fig. 3). The flow of these new injectors ranged from 1.65-mL/sec to 2.01-mL/sec at a test pressure of 400-kPa. MSU tested the injectors at a test pressure of 400-kPa, on-time of 6-ms, at 2400 RPM and found that the injectors flowed 30.7% more than the stock units. This test information was used in selecting fuel-mapping parameters. In addition to the eight injectors mounted in the stock intake manifold location, four additional injectors were mounted in front of the intake manifold, downstream from the supercharger. These injectors were supplied fuel from the fuel rail. They were controlled by the supercharger's microprocessor and only used under power boost conditions. They provided the extra fuel to maintain the proper air/fuel ratio for the increased airflow provided by the supercharger.

Fuel Rail – As part of the cold-start strategy, new fuel rails which contained electric heaters were fabricated. The new rail was cast from aluminum and then anodized to assure compatibility with the E85 fuel. The details of the heating system can be found in the cold-start/ driveability section of this paper.

Figure 3. Fuel injectors

Fuel Pressure Regulator – The stock fuel pressure regulator was replaced by an E85 compatible, adjustable pressure regulator manufactured by Paxton (P/N 8001690). This regulator was fully adjustable from 240-620 kPa and was vacuum compensated for load. With the adjustable pressure, the fuel flow rate could be finely tuned for optimum performance. The regulator was mounted in the stock position on the fuel rail.

Fuel Tank – The fuel tank was determined to be ethanol compatible. However, the sending unit seal was replaced with an ethanol compatible component provided by General Motors.

Flame Arrestor – A flame arrestor could not be designed without first knowing how the vent/filler tube system on the vehicle was constructed. The vent/filler assembly on the Chevy Silverado was quite different than most, in that the filler tube was encased inside the vent tube. The vent tube was a 50.8-mm inside dia. flexible hose with a 30.5-mm inside dia. flexible hoses serving as the fill tube inside the vent hose. It was determined that the easiest way to install a flame arrestor would be in this flexible hose assembly between the box of the truck and the fuel tank. It was determined that the flame arrestor body would be constructed out of aluminum tubing and aluminum plate machined into spacers, then anodized for ethanol compatibility (Fig. 4). The flame arrestor body would have inserts made of stainless steel mesh screening or expanded stainless steel, (similar to the arrestor material in the 98 Ethanol Vehicle Challenge Chevrolet Malibu). Stainless is ethanol compatible, thus there are no coatings required for compatibility. The aluminum tubes were assembled with aluminum spacers that were pressed in and then welded for reliable shift resistance so the stainless inserts would not be crushed by the tubes shifting. After the stainless material was inserted, the arrestor was installed into the filler hose that was an OEM piece on the Silverado (Fig 5).

Figure 4. CAD Drawing of Flame Arrestor

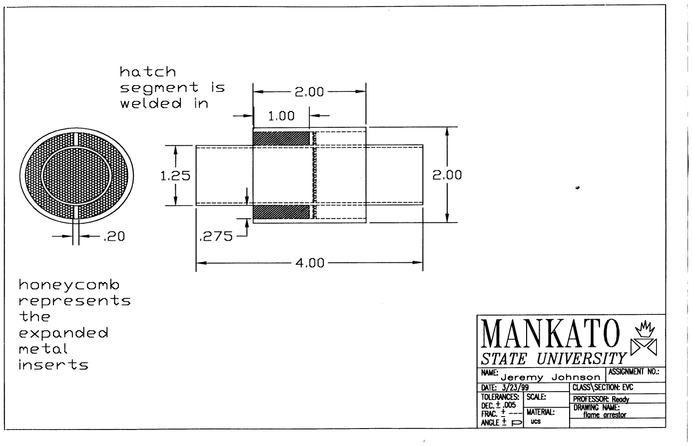

Figure 5. Picture of Flame Arrestor

MECHANICAL SYSTEM – Modifications to the engine's mechanical system were intended to raise thermal efficiency, reduce pumping losses, and optimize performance to match the high octane characteristic of the E85 fuel.

Compression Ratio – The stock compression as specified by Chevrolet was 9.5:1. When the engine was disassembled and all components measured, the actual calculated compression ratio turned out to be 9.4:1. With E85's high motor octane of 89, and research octane of 107 (SAE paper #820002) and also based on previous MSU ethanol fuel engine research (SAE paper #952749) compression ratios up to 14:1 worked well with E85. Even when NOx emissions were a factor, 12.5:1 could be used and still fall within low emission vehicle standards. However, with the supercharger providing boost beginning at 2000 RPM at wide-open throttle, a compression ratio goal of 10.5:1 was chosen. This resulted in a thermal efficiency gain under all engine operating conditions, while tolerating the extra manifold air pressure provided at wide open throttle without causing detonation. Several methods of increasing the compression ratio to this level were considered (milling the heads, thinner head gaskets, or using pistons with less or no dish). It was decided to mill the cylinder heads. The volume of the combustion chamber was measured (Fig. 6) along with the area at the cylinder head surface. Changes in the pistons were not desirable because of need for break-in. After some calculations were done (as shown below) it was decided to mill the heads 0.152-mm to gain 1.0 compression point. This, combined with the 61.5 cc original combustion chamber volume, 11.2 cc head gasket volume, - 1.1 cc deck height volume, 7.6 cc piston dish volume, and 665.9 cc cylinder displacement, created the desired 10.4:1 compression ratio.

$$CR=\frac{Disp+ccv+hgv+dhv+pdv}{ccv+hgv+dhv+ddv}$$

Original compression ratio

$$CR=\frac{665.9+61.5+11.2+(-1.1)+7.6}{61.5+11.2+(-1.1)+7.6}=9.4:1$$

New compression ratio

$$CR=\frac{665.9+53.1+11.2+(-1.1)+7.6}{53.1+11.2+(-1.1)+7.6}=10.4:1$$

Cylinder heads – The area of the combustion chamber was found by using graphing paper which had ten squares per inch in each direction, each square then being .01 inch square. The area of the combustion chamber was found to be 9.55 square inches, which when converted to SI is 61.60 square centimeters (as shown below).

9.55 sq.in.*(6.45 sq.cm/1 sq.in.)=61.60 sq.cm.

To raise the compression ratio one point, the combustion chamber volume had to be reduced to 53.1 cc, which is a reduction of 8.4 cc. With the area of the combustion chamber being known, the amount of milling needed to be figured out (as shown below).

61.60 sq.cm.*height (cm) = 8.43 cc   height=0.137 cm

Since the combustion chamber walls sloped in towards the valves, it was decided to mill the cylinder heads 0.152-mm. After the heads were milled, the volume of the combustion chamber was again measured and found to be 53.2-cc. No problems between the mating surfaces of the cylinder heads and intake manifold were encountered when the engine was reassembled because the thick, semi-firm gasket made up for the slight angle change.

Valvetrain geometry – The heads were milled changed the geometry of the valvetrain. Three options were considered to compensate for this fact: using shorter pushrods, shortening the stock pushrods, or using shims underneath the rocker arm supports. The team chose to use shims underneath the rocker arm supports. Trigonometric formulas were used to figure out what the thickness of the shim should be. The rocker arm ratio was found to be 1.5:1, thus moving the valve down 0.229-mm, due to the milling of the cylinder head. After calculations were done, it was figured that the shims needed to be 0.091-mm thick. An aluminum sheet was used to make the shims. It was then sheared into pieces that were placed under the paired rocker arms for each cylinder.

Short block – No changes were made to the short block part of the engine.

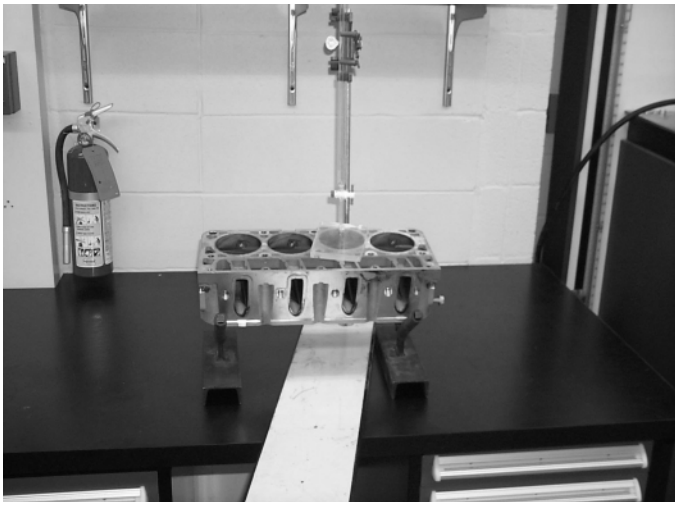

Figure 6. Method of Measuring Combustion Chamber Volume

IGNITION SYSTEM – Modification of the ignition system was minor and only involved spark plugs and wires. All other components and control strategies functioned properly in the stock configuration.

Spark Plugs – Spark plugs that were two heat ranges cooler were selected to run in the E85 motor. This was based on previous experience with ethanol's hotter burning in the combustion chamber, the effect of the increased compression ratio, and the supercharger.

Spark Plug Wires – New spark plug wires were selected from MSD (P/N 32819) because of better resistance to underhood temperatures and higher level of secondary insulation. Also high temperature shields were used to protect the spark plug wires from the high underhood temperatures created by the exhaust headers. These shields that go over the spark plug wire boots were Taylor brand "Fireboots" (P/N 2522).

LUBRICATION SYSTEM – Based on 1998 lubrication system recommendations for flex-fuel E85 vehicles sold by both Ford (3.0 L Taurus) and Dodge (3.3 L Caravan) special attention was paid to proper lubricant and oil filter selection and the development of an appropriate lubrication system maintenance schedule.

Oil – Mobil 1 0W30 synthetic oil was selected for this vehicle because the low viscosity at low temperatures helped with the cold-start.

Maintenance Schedule – With the long-term effect of E85 on engine oil being a somewhat unknown factor, a conservative two-step approach to oil change intervals was taken. First, a 4830-km oil and filter change interval was established. This matched the severe service recommendation from Chevrolet for the 3.1-L Malibu and was also consistent with that of Dodge's 3.3-L flex-fuel Caravan. Second, it was decided to perform oil analysis at intervals of 2415-km for the first 24150-km of ethanol operation. Then, based on the analysis of factors such as water build-up, acidity, and metal contamination, the service interval could be modified.

EMISSIONS SYSTEM – The overall purpose of the emission system was to reduce, to the lowest possible levels, all pollutants entering the atmosphere from the tailpipe. Changes to the emissions system included the addition of electrically heated catalysts (EHC's) and auxiliary air injection.

Electrically Heated Catalytic Converters – Since the majority of harmful emissions occurred during cold starts before the catalysts achieve operating temperature, this area received the most attention. Two EHC's supplied by EMITEC (Fig. 7) were attached ahead of the stock converters in the Y-pipe. This operation was performed by removing the fairly straight sections of the Y-pipe. Then, the front cone of the stock converters was cut off and used as a reducer back down to the 5.72-cm pipe in front of the EHC's. The catalysts were placed as close to the engine as possible to make the best use of engine exhaust heat. The EHC's served to react with exhaust gases on initial cold start and to aid with faster light off times of the main catalytic converters. The goal was to have the EHC's reach their minimum operating temperature of 300-degrees C within 10 seconds of activation. Each EHC consisted of a coated heating grid 70-mm in diameter and 12-mm long with a cell density of 62 cells per square cm, (c/sq.-cm). Each one also contained an additional supporting matrix 70-mm in diameter and 74.5-mm long with a cell density of 93-c/sq-cm. Each EHC had a current draw of 175-amps. Before installation, the EHC's were tested to determine required on-time. The operating temperature of the catalysts needed to be maintained between 300 and 600-degrees C. Monitoring the rate of heat up and cool down times helped to determine a control strategy.

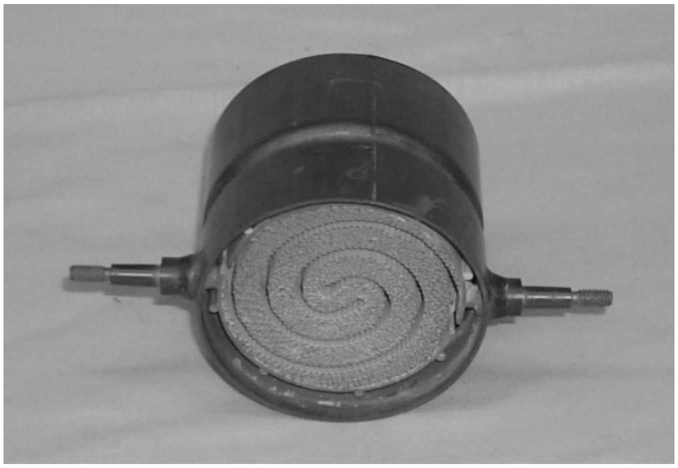

Figure 7. Lubrication System

Air injection – To further aid in quick catalyst light-off times, a secondary air injection system was added. An electric air pump from GM was used (Fig. 8). This model was standard equipment on Silverados sold in California. An air injection manifold from a 1983 Chevrolet 7.4-L engine was installed on both headers. These units had to be welded to the headers on each runner. Air tubes were placed as close to the exhaust port as possible to inject the air where the fuel was the warmest possible so that most of it would burn with the extra oxygen. This system was used during cold starts to help oxidize exhaust gasses and to raise the exhaust gas temperature (EGT). The engine was also run rich during this time (see the PCM CALIBRATIONS section of the paper). The reaction between the extra fuel and air in the exhaust aided in raising EGT, which helped heat the catalytic converters. EGT was monitored upstream of the catalysts to determine the proper amounts of air and fuel to be added. The goal was to achieve an EGT of 300-degrees C after 30 seconds at the catalysts. Once up to operating temperature, the air injection was not used because it would increase NOx emissions by providing an overly lean mixture to the three-way catalytic converters.

Figure 8. Air Pump

PLC – A programmable logic controller (PLC) was used to control several functions including the EHC's, air injection, and fuel heaters. The unit chosen was a Siemens model # 6ES7 212-1AA01-0XB0 (Fig. 9). This unit could be programmed with a PC or laptop computer in order to customize control strategies. The PLC was mounted in the center console and the wires were run down through the floorboards to all the components it controlled. The PLC was powered constantly in a rest mode that drew an average of 30-mA. The PLC turned on the EHC's, fuel rail, and thermo batteries when triggered by a switch on the driver's door handle. There was also a secondary switch, triggered by the ignition, that controlled the air pump, the timer for the battery isolator, and the EHC's.

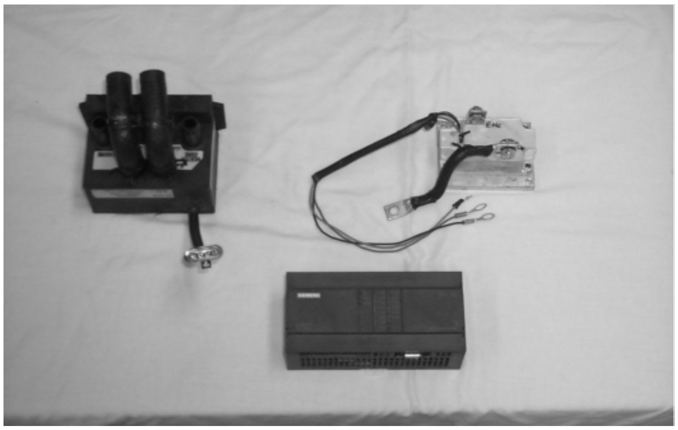

Figure 9. PLC and Controlled Components

PCM CALIBRATIONS – This was a new concept that GM came up with in 1999, for every ethanol team. GM committed to do a PCM flash once a week for each team by providing a disk with certain values that could be changed. MSU's team selected three areas to be modified: air/fuel ratio, cold start enrichment, and warm-up idle speed.

Air/fuel Ratio – The air/fuel ratio was adjusted by using the calibration software provided by GM. Using the information supplied by the fuel manufacturer, the calculated stoichiometric air/fuel ratio was 9.9:1. Since ethanol required a richer ratio than gasoline, the equivalency ratio was increased at, or near, wide-open throttle.

Cold Start Enrichment – Modifications were made to the calibrations supplied by GM, which instructed the PCM to run the engine much richer when the intake air temperature was below a certain value. This, in combination with the air injection, allowed for a rapid warm-up time for the catalytic converters, which then lowered the overall emissions. A strategy for using an air pump, to burn extra fuel in the headers, was developed to warm-up the catalytic converters more quickly. This only occurred for a specified length of time. The time was controlled by the PLC using inputs from the PCM.

Idle Speed – The idle speed of the truck during the warm-up cycle was also raised to allow more exhaust flow through the catalytic converters. This shortened the time it took to heat the converters to closed-loop operating temperatures.

COLD START / DRIVEABILITY – E85's vapor pressure of 38-83 kPa @ 38°C compared to 48-103 kPa @ 38°C of gasoline caused less fuel evaporation. At colder temperatures this could cause poor starting and driveability problems during engine warm-up. Also, the fuel's high latent heat of evaporation (836-kJ/kg for ethanol, vs. 349-kJ/kg for gasoline) created lower temperature intake into the cylinder, making it even more difficult to transform E85 from a liquid into a vapor. For these reasons, a coolant heat storage system and a heated fuel rail system were used to provide additional heat into the engine during the cold start and engine warm-up portion of a typical drive cycle.

Heat Storage Unit – In order to enhance the cold startabilty, driveability, and fuel economy, while reducing emissions, two heat storage devices were added to the vehicle (Fig. 10). These devices were manufactured by Centaur Thermal Systems, Inc. The system was 168-mm outer diameter by 355-mm long and weighed 2.5-kg when empty and 7.9-kg when full with coolant for each unit. The units were constructed of stainless steel and were controlled electronically by an Integrated Control Unit, (ICU), which was mounted on the end of one cylinder. This ICU was a pump and valve system set up to control the delivery of the hot coolant to the engine and keep it there until the thermostat opened. The units became part of the cooling system since they were set up in series with the cooling system.

Engine coolant from the previous operation cycle was stored in two vacuum-sealed containers. Starting at 100-degrees C from the last engine run cycle, using a 50% mixture of ethylene glycol and water, (combined specific heat of .58), the 5.4-kg unit could store 266.2- Calories of heat energy above the ambient temperature of 15-degrees C. Temperature drop rates of 5-degrees C/hour were experienced. This drop, over a 12-hour period, left a coolant temperature of 40-degrees C, and 78.3-Calories of heat energy. Just prior to starting, the heat was circulated into the engine's block. This aided cold-start/driveability and cold-start emissions. This process took about 30 seconds and helped the engine heat-up so that it reached its maximum efficiency faster. The unit was then recharged as the engine heated-up. Two 5.0-L units were chosen and installed behind the front bumper, using specially fitted brackets.

Fuel Rail Heater – The original fuel rail for the truck was measured and a CAD drawing was created. This served as the blueprint for the replacement rail. The fuel rail heater elements were cast in the aluminum rail. The heater consisted of two heating elements in each rail that were rated at 950 Watts per rail. All aluminum that was exposed to E85 was anodized to assure compatibility. The heaters provided an optimum starting temperature of 37 degrees C and were run by the PLC and an automotive starter solenoid (WELLS P/N F492).

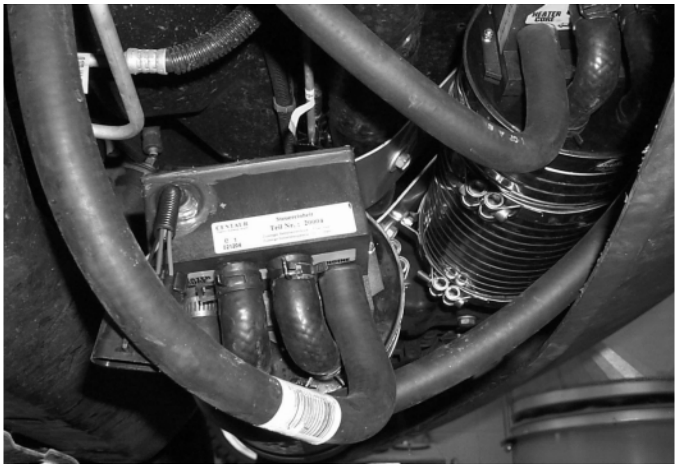

Figure 10. Coolant Storage Batteries

POWER BOOSTING – One of the goals of the 1999 Ethanol Vehicle Challenge was to maintain or increase vehicle performance. MSU's team chose to increase the engine power and thus improve vehicle performance. Two different methods were used to improve volumetric efficiency: supercharging the engine and modifying the exhaust system. These two modifications increased both the power and torque produced by the engine.

Supercharger – a twin-screw supercharger. This twin-screw design was more volumetrically efficient than a conventional roots-type blower (Fig. 11). The supercharger that we received was a prototype model that Whipple was using for testing. The supercharger was not yet on the market but Whipple was very generous for providing a prototype. Testing by Whipple on 1996-97 Chevrolet Vortech 5.0-L and 5.7-L engines showed an increase of power and torque no less than 48% and no greater than 50%. These tests were done on gasoline fueled motors and did not reflect the changes that MSU's team had made to the engine's fuel and mechanical systems. This supercharger was a compact unit putting out an average of 34.5-kPa to 41.4-kPa. This enabled the volumetric efficiency of the engine to be increased by force injection instead of raising the compression ratio any higher than 10.4:1. The reason for keeping the compression ratio at that value was the limited deck thickness in the combustion chamber. While the compression ratio could be higher for an ethanol-powered vehicle, the supercharger made up the difference. The Whipple Charger was run by the serpentine belt and was located on the passenger side of the air intake plenum. The throttle body had to be moved to the intake side of the supercharger and required the throttle cable assembly to be moved to the rear passenger side of the intake plenum. The supercharger contained an adapter that attached to the front of the intake plenum that contained two throttle enrichment injectors for extra fuel injection at higher boost levels. It was discovered that two more injectors would need to be added because of ethanol's need for more fuel flow, so the adapter was modified to contain four injectors. This adapter was cast aluminum that was not ethanol compatible, therefore it was anodized.

Figure 11. Supercharger Installed

Exhaust – Borla provided the team with two basic areas of exhaust flow improvement (Fig. 12). The first was a set of headers that replaced the stock exhaust manifolds. These headers were sent to Jet Hot and then were given a thermo-coating to reduce underhood temperatures and keep heat in the exhaust to help catalytic converter light-off time. It was found when installed that the underhood temperature was still too great and a header-wrap (Thermotec P/N THE11248) was used, which further reduced under-hood temperature. The second area of needed improvement was from the Y-pipe to the rear of the vehicle. The Y-pipe converged duel exhaust to single exhaust and contained the catalytic converters. The Borla pipe and muffler was less constrictive when tested and added better exhaust flow performance. The overall reduction of exhaust gas backpressure allowed for better flow while the supercharger was providing boost and also compensated for the flow reduction created by the addition of the EHC's.

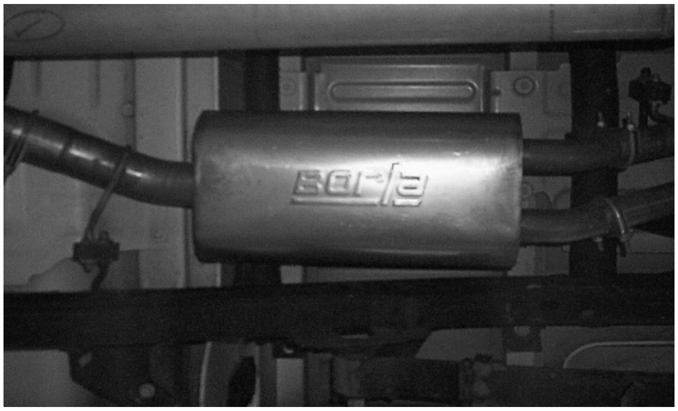

Figure 12. Exhaust System Components

BODY AND CHASSIS – Within the 1999 Ethanol Vehicle Challenge competition rules, only minimal modifications to the body and chassis were allowed. However, there were some unrestricted areas so an attempt was made to maximize performance where possible.

Aerodynamics – A body kit was obtained: the Searing Silverado package from Performance West Industries. The kit included the following items: tailgate, rear roll pan, front bumper cover, side moldings, and fiberglass bed cover. These items improved the aerodynamics as well as the styling of the truck. They were installed and integrated into the graphic paint scheme, which featured MSU's school colors.

Battery Relocation – It was found that the truck would need a second battery to run added accessories such as the Electrically Heated Catalytic converters and the emissions air pump. While these systems were only active during warm-up of the engine, they were found to draw too much current for a vehicle with one battery. With that in mind, an AC-Delco model 76-7YR rated at 975 cold cranking amps (cca) was installed. This battery also had a reserve capacity of 150 minutes. Since the engine compartment was full of components, the battery was mounted on the frame of the vehicle. A battery box was constructed from 4.8-mm flat steel with three 12.7-mm carriage bolts on the back that attached it to the frame. The competition rules stated that no modifications could be made to the original frame, so, three existing holes behind the passenger side front wheel were used. The top of the battery tray was made from 4.8-mm thick angle iron and was removable with two 12.7-mm bolts, 178-mm long that held it to the side supports.

Secondary Battery Cables – The battery cables used were 2/O gauge welding cable rated at 600 volts. Side post terminals made by Standard were bolted to the battery and heat shrink tape was applied over the exposed junction between cable and terminal. It was also thought that a quick disconnect would be handy for the purpose of charging or battery removal. Therefore, a quick disconnect, made by Standard, was installed (PN SST311.

Battery Isolator – Testing showed that the secondary battery would only be used during the warm-up cycle of the vehicle and did not need to be charged all of the time, so a battery isolator was incorporated into the charging system. This unit (Hellroaring Technology model BIC-75150) was mounted up in the front of the truck, close to the original battery on an aluminum plate. It was installed with 8-gauge wire going from the positive battery cable to the isolator, then from the isolator to the alternator. The isolator was a component also controlled by the PLC. This allowed it to be programmed to charge the battery when needed.

Wheels – The wheels selected were manufactured by American Racing Equipment (ARE Nitro). These were one-piece cast, polished aluminum five-spoke wheels. They retained stock rim measurements. These wheels were licensed by GM.

Tires – The tires on the vehicle remained stock (Firestone Wilderness AT P265/75R16).

Sway Bars – Since the truck had the Z-71 sport suspension package, the stock sway bar and suspension components were retained.

Fire Suppression – A standard 2.27-kg dry chemical (5A10BC) fire extinguisher was mounted inside the vehicle within easy reach of the driver. In addition, a 2.27-kg halon fire suppression system was designed for the vehicle. The halon extinguisher had discharge nozzles located in the engine and passenger compartment. A release cable accessible to the driver activated the system.

PRELIMINARY TEST RESULTS

This testing was completed at MSU before the competition.

INJECTOR FLOW – The results for the stock injector flow vs. replacement injector flow are in Table 1.

Table 1. Fuel Injector Flow

Injector	Flow (ml/sec)
Stock	1.40
Replacement	1.83

ELECTRICALLY HEATED CATALYSTS – It was discovered that the time it took to heat up the catalysts to 580 degrees C was 17 sec. This temperature was enough for cold start conditions.

EXHAUST SYSTEMS – The stock exhaust system and Borla exhaust were tested for kW increases. Also, the Borla exhaust was tested with E85 as the fuel to discover any kW changes the E85 produced (Fig. 12). E85 with the Borla exhaust had the highest kW values, and stock system had the lowest kW values. Table 2 reflects the peak kW and rpm @ peak kW for all systems.

Table 2. Exhaust Horsepower Results

System	**Peak kW**	**Peak kW RPM**
Stock	141kW	4300 rpm
Borla	168 kW	4900 rpm
E85 with Borla	175 kW	4750 rpm

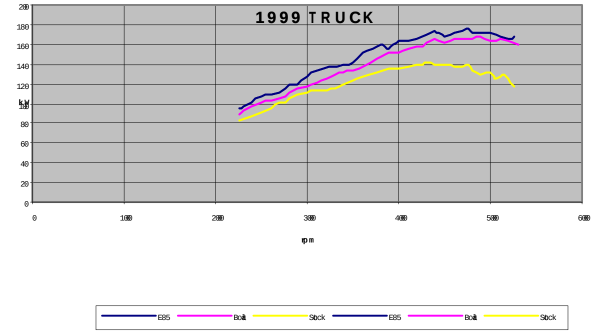

Figure 13. Exhaust System Performance

STOCK FTP EMISSIONS – Five FTP tests were done when the vehicle was stock, (running regular gasoline). The average results from these five tests were combined in Table 3.

Table 3. FTP Emissions Test

Emissions	**Stock, regular gas**
Total Hydrocarbons	0.157 g/mile
CO	1.544 g/mile
NOx	0.227 g/mile
CO2	603.60 g/mile
Fuel economy	5.7 km/L

STOCK HIGHWAY FUEL ECONOMY TEST RESULTS – Five Highway Fuel Economy Tests were performed and the averaged results are in Table 4.

Table 4. Highway Fuel Economy Test

Emissions	**Stock, regular gas**
Total Hydrocarbons	0.062 g/mile
CO	0.707 g/mile
NOx	0.213 g/mile
CO2	430.21 g/mile
Fuel Economy	8.5 km/L

FINAL TEST RESULTS

Overall, the MSU team placed a somewhat disappointing eighth. Most events went well and the truck performed as expected. However, one circumstance created a major problem that drastically effected two of the events. During the final minutes of the FTP emission test, two spark plug wires became separated from the spark plugs. This caused massive hydrocarbon emissions and resulted in total failure of the emission test. The quarter mile acceleration directly followed the emission test and the team had no time to diagnose the problem. This resulted in massive misfiring and very poor performance in the first two attempts on the acceleration course. After the first two runs the team had a chance to open the hood and immediately found the problem wires and reconnected them to the spark plugs. The final run on the acceleration course began with so much power that the driver backed off the throttle to regain traction and then feathered the throttle to maintain traction. The run resulted in a respectful third place but did not demonstrate the true capability of the engine. The engine power level was demonstrated the next day when the truck won first place in the hill climb event where each vehicle pulled a 7000 pound trailer up a seven percent grade over 2000 feet.

The spark plug wire problem was later analyzed by the team. Outside opinions were also solicited from a number of individuals. The final most probable cause was determined to be that the grease used to install the spark plug boots on the wires, along with very supple boots, had trapped and compressed air in the boot. Then, when heated to levels higher than normal during the emission test, the air pressure built up to a level sufficient to blow the wires off the plugs. The plug wires were also located directly under the supercharger and may have not been fully connected to the plugs.

Final point totals and specific results compared to other teams in the competition can be found in the SAE Special Publication covering the 1999 Ethanol Vehicle Competition.

RECOMMENDATIONS

Based on the experience gained through this project, MSU's student team specifically recommends that:

- Government, industry, and education continue to cooperate to meet the goals of the Clean Air Act and the Energy Policy Act through research, promotion, and the introduction of more alternative fuel vehicle choices for consumers.
- Industry, government, and other groups continue to provide opportunities, such as the "1999 Ethanol Vehicle Challenge".
- Colleges and universities continue to commit resources (funding, space, personnel) which enable entry into these types of competitions.
- Future engineering and engineering technology students take advantage of the opportunities provided by such vehicle competitions.
- Present students, involved in these competitions commit themselves to support future educational opportunities such as these competitions provide.

CONCLUSIONS

From a technical standpoint, the E85 1999 Chevrolet Silverado has shown that an existing vehicle, designed for gasoline use, can run well without modification on ethanol concentration approaching, but not quite reaching 85%. With only slight modifications (injector flow and fuel pressure) it can run well on E85. At this point, the conversion to E85 could be completely transparent to the owner. However, as the ambient temperature drops, cold-start and driveability become problems. With the addition of a cold-start system, this problem can be solved. With relatively minor modifications to a stock engine, the vehicle will run well, but not be taking full advantage of E85's potential. This potential lies in the increased thermal efficiency that can be obtained through basic engine design modifications (compression ratio, displacement, ignition timing, and camshaft design). MSU's E85 conversion attempted to optimize the vehicle for E85 use in a cost-effective manner while keeping the cars normal operation transparent to the driver. MSU's student team feels this attempt has been successful.

From an educational standpoint the "real" goal of this project, and the "1999 Ethanol Vehicle Challenge", was to provide an opportunity for learning. Learning not only involved the technical/automotive aspect, but also communication, time and budget management, and teamwork. The team knows this goal has been successfully achieved.

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