The Newest Silverado: A Production Feasible Ethanol (E85) Conversion by the University of Nebraska-Lincoln

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ABSTRACT

A 1999 Chevrolet Silverado was converted to dedicated E85 (85% ethanol and 15% unleaded gasoline) use by the EVC 2000 Team from the University of Nebraska-Lincoln. The goal was to develop a commercially producible vehicle which was capable of performing beyond the expectations of a stock vehicle with respect to emissions, cold start, driveability and fuel economy.

The design strategy optimized a combination of General Motors (GM) LS1 and LM7 engine technologies to produce a 5.7L engine with improved horsepower and torque capabilities. Cold starting and driveability were improved through the use of air and fuel heaters and emissions were minimized through the innovative use of exhaust gas recirculation, rapid exhaust port oxidation and phase-change catalytic converters. Control strategies for the engine and auxiliary controls were configured for optimum engine performance and acceleration was optimized through the use of an electrically driven supercharger and a new air intake system. Other modifications included a performance transmission overhaul and vehicle appearance package.

INTRODUCTION

The 2000 Ethanol Vehicle Challenge (EVC) culminates a three-year, 16 school competition emphasizing the importance of alternative fuels development. The main goals of the Challenge were to encourage innovation in ethanol (E-85) vehicle technology, specifically in terms of vehicle performance, emissions control, fuel economy and cold starting; collect data to define the state of ethanol (E-85) vehicle technology; and provide student engineers with a valuable hands-on learning experience in a real-life interdisciplinary engineering project. [1]

The platform chosen for the 2000 Challenge was the same 1999 Chevrolet Silverado 4x4 pickup (Figure 1) that student teams converted for the 1999 Challenge. All stock Silverados were equipped with the 5.3L V8 LM7 Vortec engine. Since the vehicle platform was not changed for 2000, student teams were given a complete year, starting at the end of the 1999 Challenge and concluding in May of 2000, to refine or completely re-engineer their entries from the previous Challenge.

Changes for the 2000 EVC competition included a reduction in the cold-start temperature from 20°F (-7°C) to 0°F (-18°C) and elimination of cold-start emissions testing; on-road fuel economy testing included a trailer towing portion as well as highway portion (without trailer); and the hill climb event was eliminated.

Figure 1 - The UNL-EVC Silverado

In preparation for the 2000 EVC, a team of 30 student engineers from the University of Nebraska-Lincoln (UNL) was assembled. The team included 75% new members as well as 25% returning veterans, and was broken into four main groups. The groups were assembled in conjunction to the 1000-point event scoring distribution, which focused heavily on emissions (200 points), fuel economy (200 points), cold start (150 points), and performance (125 points). The remaining 300 points were awarded for vehicle design which includes a written design report as well as an oral design presentation and vehicle design inspection. [1]

In summary, the three Ethanol Vehicle Challenges have provided students from UNL with a challenging engineering experience in which past, present, and future technology has been researched and developed in order to create a production feasible, E-85 conversion that exceeds the requirements of the competition. It also provided the students with a way to give back to the State of Nebraska, in the form of a functional justification for ethanol production.

PROJECT TIMELINE AND TEAM MANAGEMENT

Although a full year was allotted to modify the 1999 Challenge vehicle in 2000 as opposed to the six months in the previous two Challenges, time and team management were just as crucial. The extra six months allowed for further refinement of systems and components that worked well in the previous competitions, as well as extensive research and design of new components.

The team structure that was used for the previous two Challenges was maintained for 2000, which included breaking the team into four main groups. These groups included cold start, materials compatibility, controls, and engine/emissions. Each group was responsible for its specific area on the Silverado, but also worked to maintain good communication with other groups in an effort to integrate components and systems with the least amount of re-engineering.

The project timeline for 2000 was also similar to that used in the 1998 and 1999 Challenges. A total of eight months was allotted for modifying the vehicle, while the remaining 4 months were used for testing, refinement, and Challenge preparation.

VEHICLE CONVERSION

MECHANICAL

In order to increase fuel economy and power output without sacrificing engine-out emissions, the stock 5.3L V8 Vortec LM7 engine was modified to make it similar to that of the 5.7L V8 LS1 engine. These modifications were done at low cost using OEM parts readily available from General Motors.

Compression Ratio

By increasing the compression ratio in an engine the thermal efficiency is usually increased, which in turn provides benefits to fuel economy, engine emissions and power output. The stock compression ratio of the Silverado engine was increased from 9.5:1 to 11:1 by using a flat-topped piston in combination with a 0.030-inch face milling of the cylinder heads. This increase in compression ratio also helped to make up for the 20% reduction in fuel energy of E85 fuel blends.

Pistons

The stock LM7 pistons were replaced with General Motors OEM LS1 pistons, which required an increase in cylinder bore diameter of 2.99mm from 96mm to 99mm, which increased displacement to 5.7 liters. The flat top crown design of the LS1 piston as opposed to the dished crown design of the LM7 piston also provided some of the contribution to the increased compression ratio.

Platinum Coating of the LS1 Piston Crowns

In an effort to introduce platinum surfaces into the combustion chamber to further increase effective burning of the fuel, a submicron layer of platinum was applied to the crowns of the LS1 pistons using sputtering technology. Platinum allows catalytic combustion, and helps to reduce hydrocarbon (HC) and carbon monoxide (CO) emissions by catalyzing the combustion which allows the flame to propagate further without quenching. The platinum layer also created a coating on the piston surface which resisted oxidation and the resulting carbon buildup that could shorten engine life.

Platinum was deposited utilizing the process of Magnetron sputtering with ion assist. Magnetron sputtering is a physical vapor deposition process which allows for greater yields from the coating material by making use of magnetic fields. Ion assist is a process by which a bias voltage is applied to the part to be coated and allows for greater adhesion and uniformity of the coating. To prevent contamination of the surface during sputtering, the process is performed at sub atmospheric pressures.

Heads

The stock aluminum 5.3L LM7 cylinder heads were replaced with production 5.7L LS1 heads. The LS1 heads provided for a 2.8mm increase in intake valve diameter, which reduced the pumping losses of the engine. As previously described, the heads were also face milled 0.030 inches to increase compression ratio.

Exhaust

The true dual exhaust system with equalization pipe that was implemented in the 1999 Challenge vehicle was maintained for the 2000 Challenge, but the mufflers were replaced. In an effort to reduce exhaust noise, the dual Dynomax™ high flow, low restriction mufflers were replaced with dual Dynomax™ Tri-Flow mufflers.

Camshaft

A production LS1 camshaft was used to replace the stock LM7 camshaft, which increased cylinder pressures and reduce pumping losses within the engine. The dimensions of the LS1 camshaft provided for an increase in lift of 0.40mm and 0.31mm for the intake and exhaust valves respectively. In addition, increases in valve lift duration of 8° and 17° were achieved in the intake and exhaust valves respectively. The combination of these two increases created a denser charge in the cylinder which contributed to maintaining power in the engine.

Electrically Driven Supercharger

A Turbopac™ 2500 electrically driven supercharger produced by Turbodyne Technologies, Inc. (Figure 2) was implemented to further increase engine power.

Figure 2 - Electrically driven Turbopac 2500

The Turbopac™ creates 3.5 psi of boost, which aides in the production of low-end torque while eliminating constant parasitic draw and "turbo lag" which is found in conventional superchargers. The Turbopac™ operates via 12 volts, which is converted to 12-volt, 3-phase current by the control unit. This 3 phase current is used to drive a permanent magnet brushless DC motor capable of turning at 10,000 RPM for idle operation and 40,000 RPM at full boost. For the 2000 Competition, the Turbopac™ was relocated to a position directly after the air intake, which eliminated the excessive ductwork and provided better airflow than the 1999 location.

Intake System

Due to the relocation of the Turbopac™, the Airaid™ system from the 1999 vehicle was replaced with a custom air box, ram air induction and a new air filter from AutoPhysics.

Air Box and Ram Air

The air box was fabricated out of 1/16" aluminum and created a cold air dam to reduce intake air temperatures, which increased compression efficiency. Ram air induction was also routed from one of the fog lamp openings located in the front fascia to the air box using an aluminum scoop and flexible tubing. By incorporating ram air, greater volumes of air were forced into the air box for use by the engine.

Air Filter

The air box also housed a new air filter from AutoPhysics, which replaced the K&N™ filter found on the 1999 vehicle. This new filter is a 9" long cone filter with an additional inverted cone inside that allows for smoother airflow as shown in Figure 3.

Electric Fans

To further increase engine cooling and increase usable space in the engine compartment, two electrically driven aluminum fans replaced the stock mechanically driven fan. The dual 14" Perma-Cool® high performance fans each produced 2950 cubic feet per minute (cfm) of airflow at a minimal current draw of 9.5 amps. When both fans were on simultaneously they provide 5900 cfm of airflow, which is approximately 900 cfm more than the stock mechanical fan, and were capable of lowering engine coolant temperature at a rate of one degree Fahrenheit per second. Due to this rate of performance, it was only necessary to run one fan under most conditions and the additional fan was only activated under severe loading or whenever there was an air conditioning request.

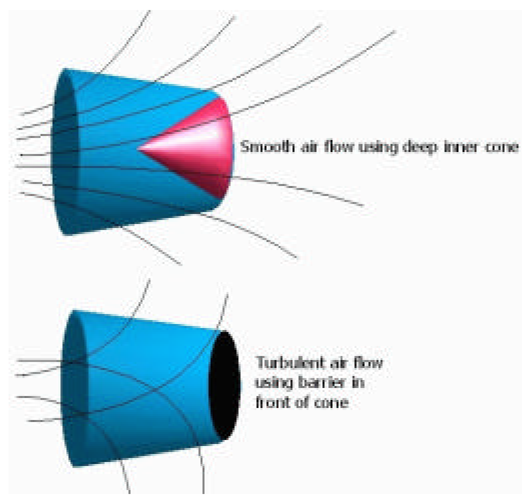

Figure 3 – AutoPhysics inverted cone air filter

Due to the removal of the stock fan and fan shroud, a custom fan shroud was made out of 1/16" aluminum. The new fan shroud was designed to pull air directly through the radiator, as opposed to through the sides of the fan, and to act as a safety guard.

Batteries

Due to the additional power demands created by supplemental systems such as the inlet air heater, fuel rail heaters, electrically driven supercharger, and electric fans, the stock battery was replaced with an Optima® deep cycle battery The battery makes use of a stronger acid, heavier paste material and Spriacell™ technology to increase cycle frequency, the power to size ratio, and vibration resistance. The Optima® Spriacell™ battery is capable of 750 cold cranking amps (CCA) and has a capacity of 67Ah.

Transmission

Modification of the OEM 4L60E transmission was required to accommodate the increased horsepower and torque of the new engine modification. The new transmission provided a stronger, firmer shift by means of an Art Carr master rebuild kit, servo kit, Transgo™ shift kit, high performance clutch plates and a Kevlar® band. The Art Carr master rebuild kit included new gaskets, seals, sealing rings, friction plates, steel plates, front and rear bushings, lip seals and a filter. The servo kit was installed to provide more hydraulic force, which increases the firmness of the shifts. Finally, the Transgo™ shift kit, which was designed specifically for the 4L60E transmission, was added to provide a firmer shift, more control, and to increase transmission durability.

Composite Driveshaft

A carbon composite driveshaft, provided by the Dana Corporation was installed. Because of its higher torsional stiffness, lighter weight, and lower rotational inertia, the carbon composite driveshaft resulted in a more effective transmission of power to the axle than the stock aluminum driveshaft.

ELECTRONIC ENGINE CONTROLLER

In an effort to optimize the PCM calibration process proposed by GM [2], it was decided that an aftermarket system should be used to develop engine control. The unit chosen was an M8 engine controller from Motec Systems with lambda control and ignition expander. The decision to use the M8 was based on the ability of this controller to use two lambda sensors and its compatibility with many of the stock engine sensors. By using the ignition expander it was possible to fire each coil separately, eliminating the need for a waste spark.

Initial Setup

Fuel

The initial fuel map was calculated based on a desired air to fuel ratio (AFR) of 10.75:1. Based on this AFR, the injector pulse width was calculated using the following equation:

$$pw = \frac{15(MAF)}{(RPM)(AFR)} \frac{1}{(INJ\_flow)}$$

MAF = Mass air flow

RPM = Engine revolutions per minute

AFR = Air/fuel ratio

INJ_flow = grams of fuel per second provided by the injector

This equation was used to create the fuel map shown in Figure 4.

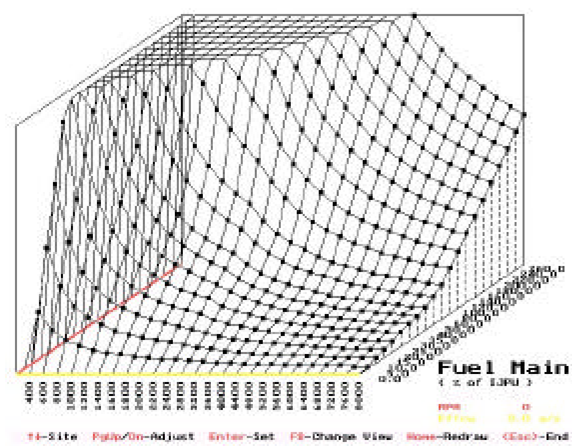

Figure 4 - Calculated base fuel map for the M8 controller for the modified 5.7L LM7 engine

Spark

The base spark table was interpolated from data found in the *2000 Ethanol Vehicle Challenge Calibration Guide* [5]. The GM "Spark Main" table was used to determine the values used in the initial M8 spark map. The GM table uses grams per cylinder of air as an axis, while the M8 uses total mass air flow (MAF). Therefore, interpolation was used to determine the values in the initial M8 spark map shown in Figure 5.

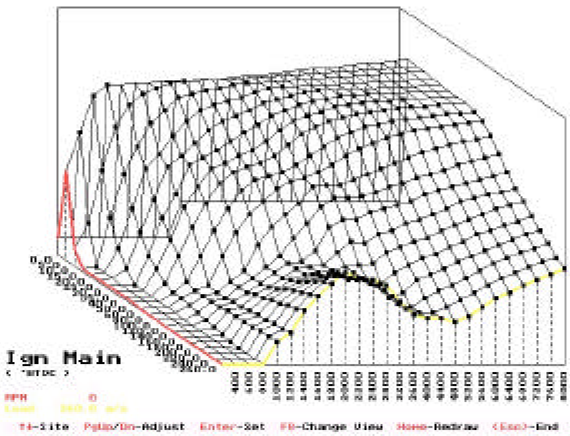

Figure 5 - Base spark table for the M8 controller for the modified 5.7L LM7 engine

Lambda Control

Two Bosch heated wide-band lambda sensors were used with the M8 to control fuel mixture. The sensors were located in approximately the same location as the stock oxygen sensors used on the Silverado. Using these sensors the fuel mixture could be trimmed to ensure the correct supply of feed gases to the catalytic converter.

Sensors

To reduce the number of diagnostic trouble codes activated in the GM PCM it was necessary to attach the Motec M8 sensor leads directly to the stock wiring. Many of the sensors, such as crank and cam position, could be directly tapped, however several sensors needed signal modification in order to operate correctly with both systems.

The GM MAF sensor output is a frequency with a range of 1500-12000 Hz. The input to the M8 needed to be a voltage with a range of 0-5 V. In order to get the voltage input, a MAF sensor with voltage output from Pro-Flow was installed in the inlet pipe.

Neither the air or engine coolant temperature sensors used on the stock engine functioned correctly with both engine controllers attached. To overcome this problem, two more coolant and air temperature sensors were installed, and wired only to the M8, while the stock sensors remained attached to the GM PCM.

<u>Tuning</u>

Drivability

After all the initial setup was complete the engine was started for the first time. For this start the M8 was given control over spark timing while fuel control was left with the GM PCM. It was discovered that at idle conditions the M8 would "jump" to an efficiency and load point that was higher than the actual mass airflow. This caused the engine to have a very rough idle. Once this was discovered, modifications were made to the spark table to compensate for this phenomenon.

After the spark table was changed to allow the engine to idle, the M8 was given full control of fuel and spark. Again the engine would not idle, and it was determined that the calculated fuel injector pulse width was supplying too much fuel. This caused the mixture to be overly rich and degraded idle quality. As was done with the spark table, adjustments to the fuel table in the idle area solved the problem and allowed the engine to idle without assistance from the driver.

Emissions and Fuel Economy

In order to tune the engine for best emissions and fuel economy the vehicle was put on a chassis dynamometer and attached to an emissions bench. Once on the dynamometer the engine was mapped, with adjustments made at every set point to optimize emissions and fuel economy.

An optimized engine is really only a compromise, in that many parameters that one wishes to minimize are inversely proportional to each other. For example, lowering HC emissions leads to a rise in NOx emissions. Because of these compromises, a list of goals was created to assist in tuning the engine for low emissions and high fuel economy. These goals were:

- Lowest possible HC emissions while keeping NOx emissions at approximately half of the 0.4000 g/mi limit.
- 20 MPG or better gasoline equivalent fuel economy during the Federal Test Procedure 1975 (FTP75) testing cycle.
- Overall emissions for the FTP75 testing cycle corresponding to the California Air Resources Board Ultra Low Emissions Vehicle (CARB ULEV) standards or better.

With these goals it was possible to start tuning the engine calibration at each set point to obtain the best combination of all parameters.

Initial testing was carried out at steady state with the engine warm. This testing involved adjusting the dynamometer load and the engine throttle position until a value corresponding to the desired table set point was achieved. After the operating conditions were set, the table values could be changed while watching the read out from the emissions bench until the optimum values were obtained.

Once the steady state testing was finished, transient conditions were investigated. The first transient considered was acceleration enrichment. To adjust this condition, the acceleration sensitivity value was changed until the engine accelerated with excellent driveability. Emissions results were monitored simultaneously to obtain a setting that gave the best drivability with the lowest emissions.

Additional transient testing was performed, that was not directly related to tuning of the engine controller, and will be discussed further in following sections.

Power

Tuning the engine for best power involved several different goals. First was to achieve the lowest possible quarter mile acceleration time, and second was to have enough power to maintain posted speed limits while pulling a 6000 lb. trailer during the on road fuel economy event.

To lower the quarter mile acceleration time, data taken from a similar engine on a Superflow SF-7100 engine dynamometer was used along with air intake and fuel requirements taken from the GM Powertrain *Engine Application Manual* [3], to provide a set of starting points for fuel and spark map changes.

The engine used for engine dynamometer testing was a 5.3L GM Vortec engine. This engine was unmodified from stock configuration. Acceleration tests were run with this engine operating on E-85 fuel, and parameter such as mass air flow (MAF) and brake specific fuel consumption (BSFC) were recorded. This data was combined with the LS-1 air intake and fuel requirements [4] to help determine set-points and the corresponding values that needed to be manipulated to prevent engine damage during initial full throttle acceleration testing.

After adjusting the predetermined set points to a calculated safe value, the data logging function of the M8 engine controller was used to finalize the adjustments during actual in-vehicle testing. Data was taken during each run, and then the individual set points were adjusted until the acceleration time was minimized.

FUEL SYSTEM

Materials Compatibility

When any vehicle is changed from E10 to dedicated E85 use, two general problems arise. First, materials that would not normally be affected by E10 may degrade in the presence of high-concentration alcohol fuels. Second, alcohols are more conductive than gasoline, which accelerates corrosion in general, especially galvanic corrosion by the increase corrosion currents produced. Aluminum, brass, zinc, and lead are examples of materials that corrode more rapidly in the presence of ethanol blends with high alcohol concentrations. Corrosion products which result from material degradation can damage and plug fuel system components.

In addition to metals, some plastics and rubber components degrade in the presence of ethanol. These components need to be replaced with an alcohol-resistant elastomer. Viton® is a flurohydrocarbon elastomer with the highest continuous heat resistance and outstanding resistance to swelling. Viton® also has a high resistance to permeation when in contact with alcohol fuels such as E85.

Component Changes for Compatibility

In order to convert the stock Silverado to dedicated E85 use, each component of the fuel system was analyzed for compatibility with ethanol. If a component susceptible to galvanic corrosion or corrosion penetration was found, they were replaced with materials that were ethanol compatible. If new fuel system components were manufactured, they were made of stainless steel or anodized aluminum and all seals and o-rings were changed to flurohydrocarbon elastomers.

Fuel Pump

An ethanol compatible fuel pump (P/N: 15038363) and main gasket, supplied by Delphi, replaced the stock fuel pump. However, within a few months of installation, the ethanol compatible pump failed and was replaced. A similar experience was encountered with the ethanol tolerant fuel pump in the UNL 1997 Chevrolet Malibu, used for the 1998 EVC, so both pumps were analyzed. Disassembly of the fuel pump from the Silverado revealed only a small site of corrosion on one of the electrical spades inside the canister, but was believed not to be the source of failure. Further analysis of the pump's o-rings, filters, and fuel lines revealed no problems or causes for failure. After reassembly, the pump's performance was tested, which resulted in an output fuel pressure of 75 psi and unhampered performance. The Malibu fuel pump was also disassembled and produced the same results. Based upon the mixed findings, we concluded that a specific component within both pumps, most likely the o-rings or gaskets, swelled due to continuous exposure with ethanol which resulted in an incomplete seal and pump failure. After the pumps were removed and allowed to set, the o-rings or gasket apparently returned to normal size and sealed properly.

Fuel Lines

Both the stock flexible fuel lines as well as the hard plastic lines connecting the fuel pump to the steel hard lines were replaced with Teflon lined stainless steel braided lines. In addition, the o-rings in the push-lock connectors, which connected the lines to the fuel pump, were replaced with Viton® B o-rings.

Steel Fuel Lines

The carbon steel fuel lines were not considered E85 compatible, due to the possibility of general and galvanic corrosion and were replaced with a set of 304 stainless steel lines. The new stainless steel lines were bent identically to the factory lines in order to retain all of the original factory-mounted positions.

Fuel Filter

An ethanol compatible fuel filter manufactured by Paxton Fuel Systems replaced the stock fuel filter. The outer case of the filter was anodized aluminum and the inner element was made of stainless steel.

Fuel Rails

It was unclear if the stock fuel rails were ethanol compatible therefore, a new set of fuel rails were fabricated by UNL. The new rails incorporated the main fuel rail section from the stock rails, which was made of a polymer material and found to be E85 compatible, but the aluminum end caps were replaced with ones made from 304 stainless steel. Each end cap was also modified to incorporate a 100-Watt cartridge heater, which was used to heat the fuel and increase fuel vaporization prior to start-up. In total four, 100-Watt cartridge heaters which were powered by a 120 Volt, 600 Watt inverter were used. In addition, all o-rings found within the fuel rail assembly were replaced with o-rings made of Viton™ B. The control strategy for this system will be discussed later in the report.

Fuel Pressure Regulator

In an effort to maintain material compatibility throughout the vehicle and fuel system, the stock fuel pressure regulator was removed and analyzed. An E85 compatible regulator, provided by Delphi, replaced the stock regulator. The o-rings on the new regulator were also replaced with Viton™ B o-rings as a precaution.

Fuel Injectors

Due to the fact that a dedicated ethanol vehicle requires 15-20% more fuel due to the lower energy content of ethanol, the stock fuel injectors were replaced with higher flow, ethanol compatible injectors. The new injectors, supplied by Delphi, flowed 3.77 grams/sec and were acceptable for both the stock LM7 configuration as well as our LS1 configuration. The new injectors also used Viton™ B o-rings to make them ethanol compatible.

Fuel Injector Test Stand

In order to test the performance and flow rates of new and used injectors, fuel pump flow rates, and injector cleaner effectiveness, a fuel injector test stand was created (Figure 6). The test stand allowed the user to test both static and pulsed flow of a single injector by means of a monostable and astable integrated circuit. The duration of the static flow as well as the time of pulse for the pulsed flow could be varied by the user to perform different tests on a specific injector. In addition to testing fuel injectors, the test stand was also used to determine fuel injector cleaner effectiveness. Injectors that were used in a dedicated ethanol vehicle have a tendency to develop a hydrocarbon resin (a syrup-like substance), which forms on the end of the injector, clogs the nozzle, and prevents atomizing flow. By mixing in the appropriate amount of injector cleaner to simulate an in-vehicle application, it could be determined which injector cleaner worked best to remove the resin.

Figure 6 - Fuel injector test stand

COLD START AND DRIVEABILITY

Cold starting and driveability are important vehicle performance characteristics regardless of the vehicle in question. When E-85 is utilized as a fuel, these two characteristics become even more important due to the properties of ethanol. E-85 has a lower vapor pressure at low temperatures, which makes it more difficult to create an ignitable vapor in the combustion chamber. For the 2000 Challenge, the cold start temperature was reduced by 20°F from the previous Challenge to a temperature of 0°F. At this temperature, the Reid Vapor Pressure (RVP) is nearly 0 psia. for E-85. E-10 has a RVP of approximately 1 psia. at this temperature, which allows for a much greater degree of vaporization. [4] Due to these criteria, it was necessary to develop a way to increase fuel vaporization and inlet air temperature at low temperatures in order to effectively start the vehicle and maintain good driveability. For the 2000 Challenge, UNL has maintained the inlet air heater from the 1999

Challenge vehicle and developed a new fuel rail with built-in cartridge heaters to counter the effects of the low RVP.

Inlet Air Heater

The air inlet heater from the 1999 Challenge vehicle was maintained for the 2000 Challenge, but it was relocated to a position closer to the throttle body. The air inlet heater was constructed of a 1000-Watt, 90-Amp, sinusoidal-shaped heating element housed in a 4" aluminum pipe that was anodized black for heat rejection. The heater was powered by 12 volts and is controlled by the circuit discussed in the electric controls strategies section of this report.

Heated Fuel Rails

Because of the removal of the air assisted injection system found in the 1999 Challenge vehicle, a new strategy was needed to increase vaporization of the fuel. This was accomplished by heating the fuel rails with four 120-volt, 100-Watt, stainless steel cartridge heaters. The heaters were used to conductively/convectively heat the fuel in the rail to a temperature of approximately 50°F (10°C) in 25 seconds. The heaters became active when the driver's door was opened and remained on until the starter was engaged. At this time, the heaters turned off to ensure that the starter would have adequate amperage. Once the vehicle is started, the heaters were turned back on for a period of 30 seconds. Power for the heaters was provided from the 12-volt battery, which was run through a 600-Watt inverter.

ELECTRICAL CONTROL STRATEGIES

Due to the removal of the cab-located laptop computer, which controlled the supplemental systems found in the 1999 Challenge vehicle, several individual electrical control strategies were developed for the 2000 Challenge vehicle. The supplemental systems which required supplemental control were the Turbopac™ 2500 supercharger, secondary air injection system, inlet air and fuel heaters, and the dual electric fans.

Turbopac™ 2500 supercharger controller

In an effort to optimize the supercharger's performance, a control system was developed which read in various engine parameters and outputted voltage and ground signals to the Turbopac™ controller to control operation. This was accomplished through the use of a Basic Stamp II Industrial microprocessor from Parallax Inc. (Figure 7)

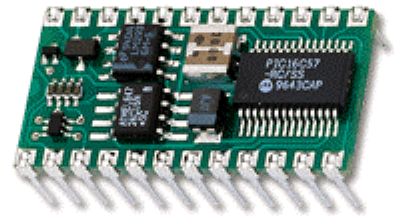

Figure 7 - Basic Stamp II Industrial microprocessor

Basic Stamp II Industrial Microprocessor

The Basic Stamp II Industrial microprocessor was chosen due to its ease of programming as well as its overall characteristics. The Industrial version of the Basic Stamp II has an operating temperature range of -40° to 85° C (-40° to 185°F) as opposed to a 0° to 70° C (32° to 150° F) range for the regular Basic Stamp II. The broader temperature range offered by the Industrial version allows the Stamp to perform during conditions similar to the cold-start event as well as those on a hot summer day. The Basic Stamp II can also read data at a rate of 20 MHz (4,000 instructions per second), which can keep up with data needs for an automobile engine. [5]

Circuitry Components

In addition to the Basic Stamp II microprocessor, several electrical components were required to complete the controller. These included an analog to digital converter, operational amplifier (op-amp), transistor, and two 12-volt relays. The completed circuit was built to fit into a 6 x 4 x 2 inch project box, which was mounted inside the cab of the vehicle.

Circuitry Mechanics

In order to determine the appropriate times for either idle or full boost operation of the Turbopac™, the controller was designed to read in two vehicle performance parameters; throttle position and the brake signal. The throttle position analog voltage signal was sent through the analog to digital converter (LTC1298), which converted the voltage to a digital binary number that could be read by the Basic Stamp. The brake signal was sent through an op-amp (LM741), which reduced the brake signal (12-volt signal when the brake was applied and zero volts when the brake was not applied) to zero or five volts, which was interpreted by the Basic Stamp as binary 0 or 1 respectively. A truth table was programmed into the Basic Stamp using PBASIC programming language and was stored in the Electrically Erasable Programmable Read-Only Memory (EEPROM) located within the Basic Stamp circuitry. Based upon the truth table, the Basic Stamp output either a 5 or 0-volt signal. If a 5-volt signal was output, that signal was passed through a transistor

(NPN2222), which increased the current of the signal and allowed the signal to throw one of the 12-volt relays.

Control Circuit Logic

The following conditions for operation of the supercharger were determined to provide optimal performance.

- Idle supercharger operation exists when throttle position is greater than 15%
- Full boost supercharger operation exists when there is 85% or greater throttle position
- Full boost will also occur when there is 25% or greater throttle position and the brake is applied

The second condition can be seen during a rapid acceleration or during a request for peak engine power and torque and the third condition was reserved for a quarter-mile acceleration run where the supercharger is at full boost prior to the vehicle leaving the starting line.

Secondary Air Injection, Heating, and Fan Controller

Another control circuit was created which controlled the secondary air injection pump (AIR), inlet air heater, and the dual electric fans. This circuit also made use of the Basic Stamp microprocessor technology.

Circuitry Components

In addition to a Basic Stamp II Industrial microprocessor, the circuit included an op-amp, analog to digital converter, two 5-volt regulators, two NPN transistors, 12-volt relay, 12-volt starter relay, and several resistors.

Circuitry Mechanics

The primary driver of this circuit was the engine coolant temperature (ECT) signal, which was used to establish various on/off points for the various components of the system. The ECT voltage signal was sent through an analog to digital converter and then into the Basic Stamp as a binary number. If a particular component of the system needed to be turned on, the Basic Stamp would output a 5-volt signal which would be sent through a transistor (NPN2222) to increase current and allow the signal to be powerful enough to activate a 12-volt relay. The two 5-volt regulators were used to step down a 12-volt engine signal so that the Basic Stamp could interpret it as a digital signal. The op-amp (LM741) in conjunction with several resistors were used as a non-inverting amplifier in an effort to prevent the ECT signal from being affected by resistance in the circuitry wires.

Control Circuit Logic

The value of the ECT signal determined which supplemental systems were activated by this circuit. The logic which this circuit is based upon is shown in Table 1.

EMISSIONS

Controlling the exhaust gas emissions from automobiles has become even more important with proposed EPA goals. The ever-increasing demand to lower vehicle emissions has brought rapid advancement in technology, and the adaptation of older methods to new components. Much effort has been spent working with alternative fuels in an effort to find an alternative to gasoline that promises lower emissions without loss of power, economy, or ease of use.

Table 1 - Logic for AIR, Heating, and Fan Circuit

Supplemental System	Criteria Needed for Operation
Cooling Fan #1	ECT > 180°F (82°C)
Cooling Fan #2	ECT > 215°F (102°C) or A/C Request
Inlet Air Heater On	Ignition = ON and ECT < 70°F (21°C)
Air Injection Pump On for 20 seconds	50°F < ECT < 85°F + Ignition (10°C < ECT < 29°C)
Air Injection Pump On for 10 seconds	ECT > 85°F (29°C) + Ignition
Fuel Rail Heaters	ECT < 40°F (4°C) Door switch = ON (30 sec. max) Starter signal = Off

Emissions status, such as Low Emissions Vehicle (LEV) or Ultra Low Emissions Vehicle (ULEV), have become attractive selling points, and the future appears to be no different with alternative fueled, fuel cell, and electric vehicles that are capable of Super Ultra Low Emissions (SULEV) or zero emissions.

Ethanol-based fuels, especially E-85 have shown that they are capable of meeting all the requirements needed of a gasoline replacement. In a properly tuned dedicated E-85 vehicle, both power and economy can be equal to or better than that of the same vehicle operating on gasoline.

The Ethanol Vehicle Challenge is no different in stressing the importance of low emissions, based upon competition scoring in which emissions accounts for 1/5 of the total possible points. Non-Methane Hydrocarbons (NMHC), Carbon Monoxide (CO), and Oxides of Nitrogen (NO_x) were tested in accordance to the Cold-Hot Start weighted Federal Test Procedure (FTP75) and points were awarded based upon gram per mile (g/mil) measurements of these three emissions.

Overview of Emissions Control Strategy

Even with an optimized engine control strategy it is still necessary to have exhaust gas aftertreatment. Current catalytic converters are capable of removing greater than 90% of HC and CO emissions once at operating temperature. During the time it takes the catalytic converter to reach "light-off" temperature it has been shown, however, that more than 60% of all HC emissions are released [2]. With this in mind the UNL-EVC team decided to implement an insulated catalytic converter design to help reduce cold-start emissions.

In addition to engine control and thermally insulated catalytic converters, several other components were added to reduce exhaust gas emissions. An exhaust gas recirculation (EGR) cooler was used to decrease the temperature of the recirculated gasses, and Rapid Exhaust Port Oxidation (REPO) was also used to help reduce converter light-off time and lower cold start emissions.

Phase-Change, Vacuum-Insulated Catalytic Converters

Design

The design for the phase-change / vacuum insulated catalytic converter was a refinement of earlier work done by the 1999 UNL EVC team [6]. The new design incorporated a short section of metal bellows at each end of the substrate, a metallic substrate, improved phase-change material (P-C-M), radiation shielding, and a better sealing system for the vacuum chamber.

Metal Bellows

The section of metal bellows at each end of the substrate helped to reduce heat transfer loss through the ends of the catalytic converter. This was the result of increasing the length of the heat transfer path from the substrate to the end of the converter assembly, where transfer to the surroundings could take place. Each section also needed to be rigid enough to support the substrate and phase-change chamber during use.

Metallic Substrate

Metallic substrates were used to help with heat transfer from the substrate to the P-C-M and vice versa. The metallic substrate has a better heat transfer coefficient than a ceramic substrate, allowing it to distribute heat more thoroughly throughout the entire substrate, during cool-down. Also, by using a metallic substrate the intramesent mat used with ceramic units could be removed, eliminating another barrier to heat transfer.

Emitec provided the substrates chosen for this design. These substrates were similar to the stock configuration, using two bricks per converter assembly, and were slightly smaller in volume and larger in surface area. The Emitec substrates also had a lower heat capacity and pressure drop, providing for shorter light-off times and less exhaust backpressure.

Phase-Change Material

Based on results of a computer model designed to simulate the heating and cooling phases of the catalytic converter, a zinc alloy was chosen for the P-C-M. This alloy provided the longest calculated cooling time for a mass of 5 kg when compared to all the alloys tested.

Radiation Shielding

In order to reduce the amount of heat lost to the atmosphere from radiation heat transfer between the P-C-M shell and the outer vacuum chamber wall, a radiation shield was installed in the vacuum chamber. The radiation shield consisted of several layers of foil wrapped around the P-C-M chamber.

Overheat Protection

The system used to prevent overheating of the catalytic converter assembly was the same as that used on the 1999 model. A small amount of hydride material was enclosed in a small packet secured inside the vacuum chamber, on the outside wall of the P-C-M chamber. As the P-C-M heated up and reached temperatures around 650° C the hydride material would release small amounts of hydrogen gas into the vacuum, significantly increasing the transfer of heat across the vacuum chamber. Once the P-C-M started to cool, the hydrogen was reabsorbed by the hydride material, restoring the low conductance within the vacuum chamber.

Modeling and Phase-Change Material Selection

As previously mentioned, in order to choose the best P-C-M a computer model was built to simulate the heating and cooling of the catalytic converter. The model used was a lumped capacitance model run using the *Enport* software package.

This model was run in two steps. First the heating section was run, and then results from this section where input into the cooling section, after which the cooling section is run. A cooling curve for a typical simulation is shown in Figure 8.

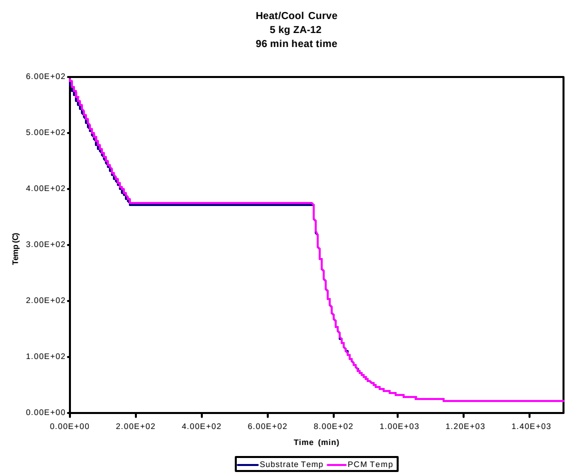

Figure 8 – Typical simulated cooling curve for the P-C-M converters

Results were obtained for many different alloys in order to determine which alloy gave the longest cooling time, while keeping the heating time within a reasonable range.

Construction

Each converter was built by first welding the two substrates together. Once this was done, flanges were welded at each end of the substrate assembly, and then a section of pipe was welded to these flanges to form the P-C-M chamber. At this point, the metal bellows were attached to the ends of the substrate assembly. Another set of flanges was welded to the ends of the metal bellows. After this, the entire assembly was placed in the furnace to heat it close to the P-C-M melting temperature (aids in alloy flow). The P-C-M was then poured in, the radiation shielding and hydride material were installed, and another section of pipe was welded to the outer flanges to create the vacuum chamber.

At this point the assembly was ready to have the vacuum pulled. The sealing system was welded to the outer pipe of the converter assembly, and a rough pump was attached to pull the initial vacuum. Once the pressure in the shell was reduced to an acceptable level, a diffusion pump was used to pull the vacuum down to the desired level, while the assembly was heated below the hydride dissociation temperature, to out-gas the materials used in the vacuum space.

Rapid Exhaust Port Oxidation (REPO)

Design

REPO is a proven way to reduce cold-start emissions. The process involves injecting air into the exhaust stream at the exhaust valve, while running the engine with a rich AFR. When this is done, the thermal energy of the exhaust gases is enough to cause combustion of the unburnt fuel, creating a rapid increase in exhaust gas temperature. The high temperature gasses help reduce catalytic converter light-off time to approximately 20 seconds with a standard converter assembly. Burning of the unburnt fuel also lowers cold-start HC emissions during a period when the engine will require a rich mixture to operate with an acceptable level of drivability.

The REPO system used for the 2000 EVC vehicle was an adaptation of the system offered by GM for use on CARB certified 1999 Silverado trucks. The GM system, however, lacked some of the features that where required for the system to work with the best possible results; namely air injection only took place at one point in the exhaust manifold.

Since the optimum system uses air injection in all the exhaust ports, the stock exhaust manifolds needed to be modified. In order to inject air into each exhaust port, stainless steel compression fittings were put in the top of each exhaust manifold runner directly after the connection to the head. Each compression fitting held a ¼ in. steel line that connected to a collector pipe that ran along the top of the exhaust manifold. Each collector pipe was attached to a check valve that stopped the flow of exhaust gasses from reaching the air pump.

The pump was the same pump used in the GM system. The pump was connected to the check valves using soft line, and is controlled by a custom controller.

EGR

Use of EGR reduces both NOx and brake specific fuel consumption (BSFC). EGR used at part load, acts as a dilutant in the unburned mixture, thereby reducing the peak burned gas temperature and the formation of NOx.

The reduction in BSFC is due to three factors:

1. Reduced pumping work with increasing EGR.
2. Reduced heat loss to the walls due to reduction in burned gas temperature.
3. Reduction in the degree of dissociation in the burned gasses also occurs which allows more of the chemical energy of the fuel to be converted to sensible energy [7].

Increasing EGR flow increases HC emissions. This is due to a reduction in burn rate, and increase in cycle-to-cycle variation in combustion. Because of this, percentages of 15-30 percent EGR are about the maximum a conventional combustion chamber can accommodate.

In an attempt to further decrease the burned gas temperatures, an EGR cooler that used engine coolant as the shell side fluid, was installed. It was hoped that this system would reduce NOx emissions during engine transient operation better than the standard EGR system.

VEHICLE APPEARANCE ENHANCEMENTS

Only slight modifications were made to the stock vehicle in an effort to maintain the original "Silverado" image as stated in the competition rules. [1] These modifications included a Dupont Chromasystem paint scheme, polishing of the stock wheels, a billet grille, and a new hood.

Chromasystem Paint Scheme

The stock vehicle arrived with the onyx black exterior paint scheme, which was sanded and scuffed in preparation for two solid Chromallusion stripes, a Chevrolet bowtie, and a large Husker 'N' which were painted using Dupont Chromasystem base/clearcoats. The bed and cab were painted with True Blazberry, while the doors and hood were painted with True Fire Prizm.

Wheel and Tire Selection

In an effort to increase fuel economy by reducing vehicle weight and rolling resistance, the chromed wheels and B.F. Goodrich tires that were used on the 1999 Challenge vehicle were replaced with polished stock wheels and Goodyear Wrangler P265/75R16 tires.

Hood

The stock Silverado hood was replaced by a custom "Good Hood" provided by Keystone Restyling Products. The new hood features two ram air inlets in the center of the hood, which added to the aggressive styling of the UNL Silverado.

PRODUCTION FEASIBILITY

One of the primary design goals established by the UNL team was to create a production feasible E-85 conversion that offered an increase in fuel economy, cold-start and performance, while decreasing emissions. This design objective was achieved through the use of many OEM parts and readily available technology.

Beginning with the engine conversion, the stock 5.3L LM7 configuration was modified to a 5.7L LS1 through the use of OEM pistons, heads, and camshaft. The items maintained from the LM7 configuration were the cast-iron block, exhaust manifolds, intake manifold, and oil pan. Slight modifications in General Motors' engine assembly could concernably produce this engine without drastically increasing vehicle price.

Engine modifications also included the addition of a Turbopac™ 2500 supercharger ($3000), a Valeo EGR cooler ($250), AutoPhysics cone air filter ($60), and an Optima deep cycle battery ($170).

The transmission was upgraded by means of an Art Carr master rebuild kit and Transgo™ shift kit which had a combined total cost including installation of approximately $1000. However, most if not all of the components used could be implemented by General Motors, which would greatly reduce the cost.

Modifications to the emissions control and fuel delivery system were accomplished through material substitutions. The stock fuel lines and filter were replaced with similar components made of 304 stainless steel and anodized aluminum respectively, while the catalytic converters were manufactured using readily available materials and technology. If mass-produced, the cost of all these components would be minimal.

Other vehicular modifications were done to improve appearance and interior comfort and would not be necessary in a production version E-85 Silverado.

CONCLUSIONS

In preparation for the 2000 Ethanol Vehicle Challenge, a student group of 30 engineers from the University of Nebraska-Lincoln converted a 1999 Chevrolet Silverado 4x4 pickup to dedicated E-85 use. The production feasible conversion focused around several key areas, which included an increase in fuel economy, cold-startability, and performance, with a decrease in vehicle emissions.

An increase in engine size from 5.3L to 5.7L through the use of OEM parts provided an increased compression ratio as well as a higher torque and power output. In order to reduce vehicle emissions, an EGR cooler was used in combination with phase-change, vacuum-insulated catalytic converters. Rapid exhaust port oxidation was also used to decrease catalytic converter light-off time. Cold-startability was improved by increasing the rate of fuel vaporization through the use of inlet air and fuel rail heaters. Fuel economy was also increased through extensive engine controller development, removal of unnecessary vehicle weight, and a reduction in rolling friction through the use of less aggresive tires. Finally, all materials were examined for ethanol compatibility and were replaced if needed, with ethanol compatible materials such as anodized aluminum, stainless steel, Viton® B and Teflon™.

In closing, the Ethanol Vehicle Challenge provided numerous engineering students with a valuable hands-on learning experience which will aid in their personal as well as educational development. The EVC also provided the University of Nebraska with a mechanism to stress the importance of alternative fuels, specifically ethanol, in a state which is one of the nation's primary producers of fuel ethanol.

ACKNOWLEDGEMENTS

The Ethanol Vehicle Team at the University of Nebraska-Lincoln would like to dedicate this project in memory of Dr. Alexander Peters who recently lost a 17-year battle with cancer. Drs. Peters and Weins provided an unparalleled learning experience from which over 100 students benefited over the last three years. Without the work and dedication of either one of them, the UNL-EVC team would not be able to compete.

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