Development of an Environmentally Friendly Snowmobile

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ABSTRACT

Clarkson University's entry for the 2008 Clean Snowmobile Challenge utilizes a 2006 Polaris FST Classic chassis and engine. The engine, a 750cc twin cylinder turbocharged four-stroke engine, has been modified to run smoothly and efficiently on E85 winter blend ethanol. The exhaust system has also been modified to incorporate a catalytic converter to further reduce emissions. These modifications have all been performed in an effort to reduce emissions and noise while maintaining as much performance as possible.

INTRODUCTION

The environmental impact of snowmobiles is undeniable. Snowmobile emissions regulations are by far the most lax of all types of engines. Table 1 shows the EPA's new restrictions for production snowmobile emissions over the next few years:

Table 1. Emissions Standards [1]

Recreational Vehicle Exhaust Emission Standards

Vehicle	Model Year	Emission standards		Phase-in
		HC g/kW-hr	CO g/kW-hr	
Snowmobile	2006	100	275	50%
	2007 through 2009	100	275	100%
	2010	75	275	
	2012*	75	200	

These figures are misleading. Although the EPA is restricting the emissions standards for snowmobiles over the next 4 years, these restrictions are still too high to force companies to significantly redesign engines for reduced emissions.

According to the National Park Service, the average two-stroke produces 150g HC/kW-hr and 400g CO/kW-hr at an average noise level of 78dBA. In an attempt to save its environmental integrity, the National Park Service has set stringent emissions regulations to be met in order for a snowmobile to enter the park. These regulations have been set based on what is known as Best Available Technology (BAT). BAT requirements are as follows: 15g HC/kW-hr, 120g CO/kW-hr, and a noise level of 73dBA. Currently, the only snowmobiles that meet this requirement are four-stroke non-turbo snowmobiles such as the Polaris FS Classic and the Arctic Cat T660 Touring.[2] These snowmobiles lack the familiar power that most consumers demand. Consumers desire the most power they can get for their money. The challenge, therefore, lies in engineering a snowmobile that is powerful, cost efficient, and clean enough to be accepted into the national parks.

Considering this challenge, it seems that a four-stroke turbocharged snowmobile is best able to achieve this status. Although not currently accepted into national parks due to emissions, these snowmobiles offer plenty of power that the non-turbocharged versions lack. This type of engine also has an exceptional potential to run much cleaner than it does presently, allowing it to meet present and future national park regulations.

The addition of E85 Ethanol into the economy has brought us the capability to further reduce emissions. The translation of this development into the snowmobile industry allows for beneficial decreases in emissions while maintaining or even improving performance.

It is therefore the main purpose of this team to modify a four-stroke turbocharged snowmobile to run cleanly, efficiently, and reliably on E85 winter blend ethanol. Secondary objectives include further reducing emissions and noise while retaining the stock snowmobile's power and price level.

ETHANOL

Ethanol (EtOH) is commonly known as a viable alternative to gasoline. According to a study by the University of Chicago's Argonne National Laboratory, Cellulosic E85 Ethanol can reduce emissions by up to 64 percent those of gasoline (per-mile CHG Emissions) [3].

Ethanol also has a higher energy potential than gasoline. Octane ratings for gasoline range anywhere between 86 and 95, whereas pure ethanol has an octane of 98 ((R+M)/2).

Ethanol has its disadvantages as well. Ethanol has four main issues:

- Phase Separation
- Increased Fuel Separation
- Compatibility/Permeability
- Solvent Action

Two of these are especially relevant when discussing the conversion of an engine to operate on E85 Ethanol. Ethanol is approximately 100,000 times more electrically conductive than gasoline. Extra care must be taken to assure that any electric current is isolated from ethanol. Ethanol also has compatibility issues with materials found quite often when dealing with engines. Some vulnerable materials include Natural Rubber, Aluminum, Brass, Copper, Lead, and Zinc. Ethanol reacts with and corrodes these materials rapidly enough that they cannot be in long-term contact with the fuel. These vulnerable materials need to be replaced with ethanol compatible materials. Alternative ethanol resistant elastomers include Buna-N, fluorocarbons, Nitrile, Polychloroprene, and PTFE. Ethanol resistant metals include Bronze, Stainless Unplated and Mild Steel, and Nickel Plated Aluminum and Brass. Engineers must be cautious as to which materials come into contact with ethanol. Extra care must also be taken to isolate ethanol from water, as it holds up to 32 times more water than gasoline. [4]

Perhaps the biggest disadvantage of ethanol is that it is less energy dense than gasoline. In order to produce the same combustion as gasoline, 1.3 to 1.347 times more E85 winter blend must be injected into the engine. This much fuel would burn at about 95 octane, giving the engine slightly more power than standard pump gasoline. This ultimately means that E85 is slightly less efficient than gasoline.

Table 2: Gasoline/Ethanol Characteristics

	Pure Gasoline	E85 Winter Blend	Pure Ethanol
Energy Density	34290 MJ/kg	25840 MJ/kg	22216 MJ/kg
Octane	86-95	94-97	98
Electric Conductivity [5]	$1x10^{-14}$ mho/cm	-	$1x10^{-9}$ mho/cm
Water Dissolution [6]	60-100ppm	-	>1900ppm
Stoichiometric AFR [7]	14.7:1	10.71	9.00:1

ENGINE AND FUEL SYSTEM

The team chose to utilize the stock Weber motor from the 2006 Polaris FST Classic chassis. The German-designed motor is a turbocharged 8-valve SOHC Parallel Twin Cylinder 749cc engine with a Bosch Motronic injection system. Rated at 135 horsepower, this engine has plenty of power to satisfy the average consumer.
This engine is the same engine that is in the BAT recognized Polaris FS, with the exception of the turbo. It is a goal of this team to modify this Polaris FST to achieve emissions and noise levels equal to or lower than that of its non-turbo brother without hurting the performance. The first step of this process was to convert the snowmobile to run on E85 Winter Blend Ethanol.

EtOH is known to react aversely with most stock components in the fuel delivery system. New components were obtained and utilized in making the system able to reliably run the E85 mixture. The team then used an adjustable fuel pressure regulator to inject the extra fuel needed to burn at the correct Stoichiometric AFR.

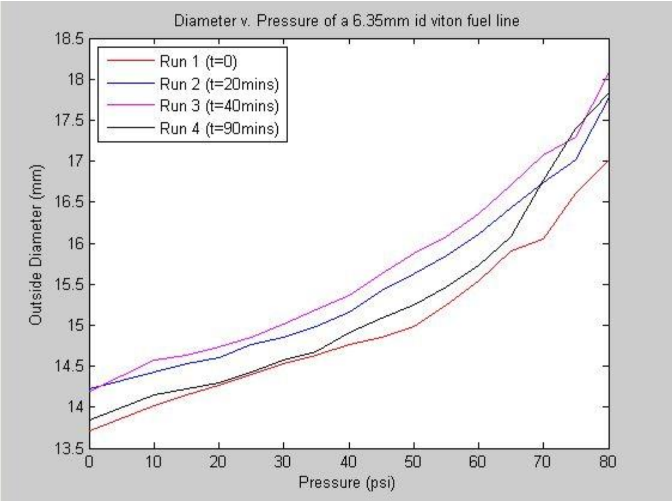
Fuel Line and Filter

It was known that Ethanol is not compatible with natural rubber, rendering the fuel lines to and from the engine inadequate. Research was done to determine which types of fuel line could serve as replacements to the stock material. Viton, a fluoroelastomer known for its resistance to ethanol, was ordered and tested for its pressure capabilities. A bicycle tire Schrader valve was clamped to one end of a short piece of Viton fuel line and the other was sealed. Pressure was applied using a bicycle pump and the diameter was recorded for every 5psi up to 80psi. The results are shown in figure 1.

These data show an increase in the diameter of the fuel line as air pressure is increased. The exponential increase in diameter is clear proof that this fuel line is not able to handle the pressures required in the fuel delivery system (58PSI continuous, with spikes up to 78PSI). Viton was therefore utilized for all low pressure applications in the fuel delivery system. This also includes the fuel line in the pickup system in the fuel tank.

Further research led the team to hydraulic fluid hose. The SAE 30R2 rated hydraulic hose is an ethanol resistant Buna-N material with fiber braid reinforcement, capable of handling up to 225PSI constant pressure [8]. This hose was utilized for all high pressure fuel line applications.

Figure 1: Pressure Testing of Viton



A sample of each replacement fuel line was immersed in E85 winter blend ethanol for one week to affirm that it was ethanol compatible. No noticeable degradation was observed, rendering the fuel line viable. Standard hose clamps were utilized in place of the stock plastic connectors to secure the fuel lines at each end.

The stock fuel filter utilized a paper filter element. The team chose to replace this fuel filter with one known to be compatible with ethanol. An OEM replacement fuel filter for a flex fuel Ford Taurus was utilized for this application.

Fuel Pump

The fuel pump in our design has to meet three fundamental standards. It must be mounted externally in order to meet competition regulations. The fuel pump must also be ethanol compatible as well as able to pump out the high pressures necessary for the fuel injection system. Currently, there are very few pumps on the market that fit these requirements. Generally, the only pumps capable of this are heavy duty large pumps designed for racing applications.

The team originally experimented with using a flex fuel Dodge Stratus fuel pump. This pump is ethanol resistant and capable of handling the higher PSI required at the fuel rail, but it is an in-tank pump. Several different methods were attempted to convert it to an inline pump, but were not able to suppress leaks that developed. Instead, the team chose to utilize a Mallory 110FI fuel pump (See figure 2). Designed for drag racing applications, this external fuel pump is rated at 75PSI continuous use. The fuel pump was converted to be ethanol resistant using a factory conversion kit (Seal/Repair Kit No. 3168).

Due to the lack of room in the engine compartment, the team chose to mount the fuel pump behind the gas tank in the rear storage box. Fuel line and electric line were extended underneath the fuel tank back to the new fuel pump location.

This pump, overkill for this application, represents one of the very few ethanol resistant high pressure external fuel pumps on the market. Although it works well for this prototype model, a pump like this would not be chosen for a mass production model. A production E85 Snowmobile will not require an external fuel pump, and most likely utilize an internal fuel pump much like the Dodge Stratus pump.

Figure 2: Mallory 110FI Fuel Pump

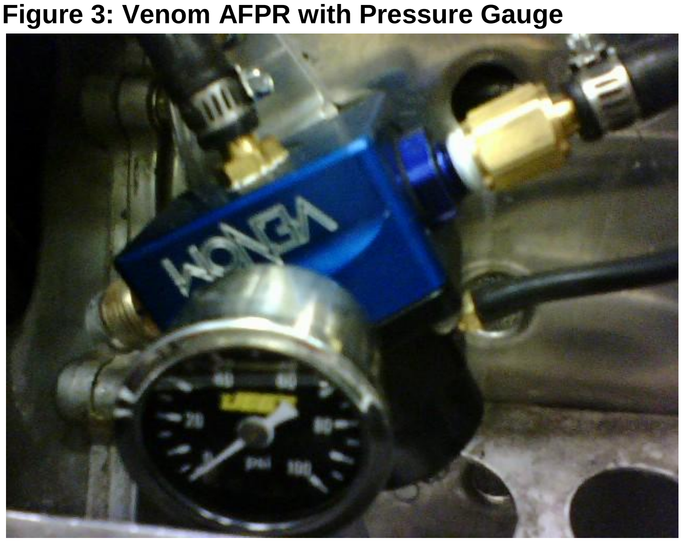
(Manufacturer's Photo)

Fuel Pressure Regulator

Because ethanol is less energy dense than gasoline, approximately 1.3 times more fuel must be injected per each cycle of the engine. There are numerous different ways to add the extra amount of fuel, including utilizing bigger injectors and reprogramming the ECU to lengthen the duty cycle. Injectors are not standardized in size, meaning that the fuel rail would most likely need to be modified to accept the injectors. Also, a new set of injectors for this snowmobile would run approximately $380, rendering this option costly and ineffectual. Also, this snowmobile is already running at the upper limit of its duty cycle. It could not be lengthened enough to solve the problem at hand Reprogramming the ECU is another ineffectual method because it requires it to be completely reflashed, an impractical option. By far, the cheapest and most simple way of achieving this is by using a fuel pressure regulator to raise the pressure at the fuel rail.

The stock FST engine runs with a fuel rail pressure of 43.5PSI. In order to inject enough fuel into the engine, the fuel pressure had to be raised to approximately 58PSI. This raise in fuel pressure also naturally reduces the target AFR from 14.7 to 10.71. The computer is still tuning the injection to a lambda value of 1.0, not realizing that more fuel is being injected into the engine. The team utilized an adjustable fuel pressure regulator (AFPR), mounted inline after the stock fuel pressure regulator, to control and raise the pressure. A Venom fuel pressure regulator was chosen for this application, as it is known to be ethanol resistant and can be adjusted within the necessary range.

Figure 3: Venom AFPR with Pressure Gauge



(Note: This picture shows the preliminary setup with brass fittings. All brass was replaced with ethanol resistant steel, anodized aluminum, and nickel plated brass fittings.)

This AFPR also has two added benefits. The team purchased a fuel pressure gauge that fits into a designated port in the FPR. This aided the team in precisely raising the fuel pressure to adapt for the E85. There is also a reference port for the turbocharger. The purpose of this is to increase the pressure at the fuel rail at a 1:1 ratio of the boost pressure. This maintains the same Air-Fuel Ratio as both air and fuel pressures are being increased proportionally. With a maximum boost pressure of 14.8PSI, the maximum pressure attained at the fuel rail is 72.8PSI.

Much like the fuel pump, this fuel pressure regulator is strictly for a prototype design. This AFPR allows for the team to experiment with raising and lowering the fuel pressures, and therefore determining the most effective pressure setting. An E85 winter blend specific production snowmobile will not need to utilize an adjustable fuel pressure regulator. Instead, the E85 fuel pressure regulator will directly replace the stock regulator. This will make the final product less complicated much more cost effective.

Miscellaneous

There is an extensive fuel pickup system inside the fuel tank of the snowmobile. As already noted, the low pressure fuel line within the tank was replaced with Viton line. All components, including a one-way valve and two pickups with pre-filters, were immersed in ethanol for a week to test their compatibility. No changes were noted in these components, and they were utilized in the final design. Zip ties were also found to be ethanol resistant by the same method, and were used to secure the pickup system together.

Concerns were brought up that the electricity in the fuel level meter would cause problems. The fuel meter on the snowmobile uses the exact same materials and connections as the one that came with the Stratus fuel pump. It was determined that the voltages in the fuel level meter are also so small that they could not possibly disturb the ethanol in the tank.

All of the O-rings in the fuel delivery system were assumed to be natural rubber and therefore needed to be replaced. Viton O-rings were ordered to replace those on the injectors and stock fuel pressure regulator. The stock O-rings were immersed in ethanol for a week along with the Viton replacements. The rubber O-rings became softer and slightly sticky with time, a sign of the ethanol reacting with the rubber.

The common NPT to hose barb fuel fittings fittings used to connect both the fuel pump and the AFPR to the fuel line are made of brass. These had to be replaced with ethanol compatible materials. The team ordered and installed nickel coated brass fittings in place of the common brass fittings. The fuel pump and fuel pressure regulator use an AN type fitting that needs to be converted to an NPT thread type. The AN to NPT adapter for the fuel pump is an ethanol resistant anodized aluminum material. Simple hose clamps were used to secure the fuel line to all components of the fuel delivery system.

HANDLING

During stock riding, the team noticed that tremendous amount of torque caused the track to slip. The stock track is a 128 inch long Camoplast track that is 16 inches wide and has 1.25 inch lugs. Although this track already has an aggressive design, the engine outputs too much power for it to handle without substantially slipping. The team chose to stud the track in an effort to give the it more grip in the snow. The team arranged 102 Woody's Gold Digger Studs and Big Nuts onto the 128 inch track. The studs were arranged in an attempt to achieve the best grip for both cornering and acceleration.

Figure 4: Stud Pattern

These studs undeniably improve traction and cornering grip, especially in icy conditions. This will improve power transfer, increasing acceleration and therefore improving efficiency slightly. As an added benefit, the increased traction also increases stopping power. The stock carbides on the snowmobile are a dual 4 inch design. The studs, combined with the carbides, will greatly improve the performance and handling over the stock snowmobile.

EXHAUST

The stock exhaust system is already one of the most effective in the industry. The four-stroke engine is clearly much quieter already than the common two-stroke snowmobile. The stock resonator is a double wall, four compartment system with a fiberglass sheet in between the two shells. The mounting system is intelligently designed and isolates the resonator from all vibrations generated by the engine. For these reasons, the team chose to utilize the stock resonator for the final design.

The team chose to integrate a catalytic converter into the final design. Catalytic converters are well known for their universal use in the automobile industry for drastically reducing emissions. Snowmobiles currently have no designated emissions reduction systems. The team chose to integrate a catalytic converter inline between the turbo and the resonator.

With the lack of space in the engine compartment, the team found it difficult to fit a catalytic converter and all extra exhaust tubing into the engine. The team modified the catalytic converter so that it replaces the exhaust pipe between the turbo exhaust port and the resonator. This design is beneficial because it takes advantage of engine heat to keep the catalytic converter hot. The catalytic converter is mounted very close to the exhaust port on the turbo, meaning that the exhaust gas is still hot. Catalytic converters are most effective when they are as hot as possible. The catalytic converter in this design is mounted close enough to the engine that the exhaust gas has little distance to cool down.

SAFETY

Numerous safety modifications were made in an effort to protect the rider from any malfunctions or accidents. A sealed battery box was fabricated to replace the stock battery box. The battery box was fabricated out of sheet steel and covered in rubberized undercoating to prevent it from transmitting any electricity. It is vented out of the bottom as per the competition regulations.

A clutch cover was also fabricated out of sheet steel and covered with a layer of Kevlar belting to protect the snowmobile and rider in the case of a belt or clutch problem. A tether was added to the snowmobile as per the safety requirements of the competition. This will automatically cut off the engine in the case that the rider was thrown from the snowmobile in an accident. To prevent objects from being hazardously kicked up from the rear of the track, the rubber snow flap was extended so that it contacts the ground.

CONCLUSION

The combination of the E85 conversion and the incorporation of the catalytic converter have created a snowmobile that is both quiet and clean, while maintaining the same power. These modifications are obviously prototype, and could be better integrated into a production model. The fuel pump would be internal, and the fuel pressure regulator would be a more specialized part fitted on the end of the fuel rail. Considering the small price increase and the slight redesign of the fuel delivery and exhaust components, it is extremely feasible for a snowmobile company to offer a clean snowmobile as part of its lineup.

Aside from offering clean production snowmobiles, it would be extremely easy for a manufacturer such as Polaris to offer aftermarket E85 conversion kits. This kit would include direct replacement ethanol resistant parts, including an internal fuel pump, an updated fuel pressure regulator, new fuel lines, new o-rings, and a new fuel filter. The estimated cost of this kit is shown in table 3.

The only downside to this kit is that it would *require* the consumer to use only E85 Winter Blend. There is an easy fix for the consumer who does not want to be limited to only E85. A second and slightly more practical kit could include an adjustable fuel pressure regulator in place of the stock non-adjustable one. It would be easy enough to design and include a simple knob to adjust the pressure regulator based on the fuel mixture. This could allow for an infinite mixture between E85 Winter Blend and E10 pump gasoline. The estimated cost of this kit is also shown in table 3.

For the consumer who does not want to worry about adjusting his or her fuel pressures depending on the mixture, the manufacturer could offer a third option. This kit would include all components in kit 2, while adding an electronic system which monitors and automatically adjusts the fuel pressure depending on the mixture. This option would utilize adapted optical sensors from Flex Fuel Automobile applications to determine the ethanol content, and automatically adjust the regulator accordingly. A rough estimated cost of this kit is included in table 3. This kit would be by far the most expensive, as it requires new electronics to monitor the fuel system. This option may be available as an aftermarket kit, but it would be much more cost-effective if it were integrated into a new production model.

Table 3: Predicted Conversion Kit Pricing

Kit Components	Kit 1	Kit 2	Kit 3
Fuel Pump	172.42	172.42	172.42
Fuel Pressure Regulator	54.99	139.95	139.95
Fuel Filter	19.12	19.12	19.12
Fuel Line	39.99	39.99	39.99
O-Rings	14.99	14.99	14.99
Adjustment System	N/A	35.99	199.99
Total:	301.51	422.46	586.46

It would also be possible for Polaris to offer a catalytic converter to replace the turbo/resonator exhaust pipe. This option could be offered at a reasonable price range ($85 to $100). This bolt-on aftermarket part, if correctly designed, could drop the snowmobile down to below the requirements for BAT in the National Parks. Few people would buy this kit unless it was required to ride certain places. Trail systems that charge a membership fee could give discounts to those snowmobiles that have a catalytic converter installed.

In essence, this design proves that the performance clean snowmobile is a reality. Snowmobiles such as this one will be clean and quiet enough to enter the National Parks, while still maintaining sufficient power thanks to the four-stroke turbocharged engine running on E85 Ethanol.

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