North Dakota State University Diesel Powered Clean Snowmobile

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ABSTRACT

The North Dakota State University chapter of the Society of Automotive Engineers (SAE) developed a clean, quiet and efficient turbo-diesel snowmobile to compete in the SAE-sponsored Clean Snowmobile Challenge in March, 2013. The snowmobile's foundation is a 2010 Polaris Turbo LX Chassis and incorporates a Kubota D902, 3-cylinder turbo-diesel, mechanically fuel injected engine. The emissions from the stock engine have been tested to meet Tier-4 standards in its original naturally aspirated configuration. The goal was to reduce the emission output to below the stock levels through the use of a partial-flow diesel-particulate-filter (DPF), water methanol injection and turbocharger. The stock chassis and drivetrain were modified to reduce noise, operate more efficient, and become lighter and smaller. Modifications for quiet operation include an under-tunnel exhaust outlet routing method, and muffler modifications in conjunction with the DPF.

INTRODUCTION

A prominent factor in today's engineering is the increasing problem associated with pollution created using current forms of transportation. It is a mutually confirmed issue that has both designer and consumer searching for better ways to accomplish the same tasks, later defined, in the most efficient way possible. The Clean Snowmobile Competition creates an environment for intellectual enhancement primarily focusing on this current issue while allowing students to "look outside the box," promote environmental safety, and maintain performance.

The Clean Snowmobile Competition (CSC) sponsored by SAE is a design competition focusing on improving several environmental characteristics. The key characteristics include lower emissions, fuel economy, ergonomics, and noise. The competition allows for a complete understanding of engineering processes from design.

Project Constraints

Engineering constraints

There are constraints that have been set into place for this project both by SAE and that of the design team. Starting with the SAE constraints a minimum of 100 miles per tank of diesel fuel must be achieved while maintaining 45 miles per hour. This falls into the endurance testing that will be conducted at competition. Furthermore, the snowmobile needs to be able to accelerate 500ft in at least 12 seconds. The engine itself has constraints that it must meet as well. The engine needs to be able to run on biofuel in the range of B0 to B9 biodiesel. Also the engine is limited to a maximum output of 130 hp, according to CSC rules. The engine oil used cannot contain any power adders of any kind. It must be able to cold start within 20 seconds after being "cold-soaked" overnight and be driven 100 feet in 120 seconds without stalling. Additionally, the use of any starting aids, such as ether, or block heaters is prohibited. The chassis used for competition must be a production chassis under the criteria that over 500 units (snowmobiles) are manufactured. The chassis must remain unaltered unless appropriate finite element analysis (FEA) documentation shows modifications are as strong as or stronger than the original. A key area of the competition is emission control. The emissions need to have a testing port installed 12 inches from the end of the exhaust opening. The overall encompassing constraint is that the snowmobile needs to be reliable for whoever the future user may be.

Primary constraints that held most focus in this project involved reducing weight and maximizing efficiency of the motor. The starting weight of this snowmobile records 768 lbf; this imposes great strain on the motor. Reducing overall static and dynamic weight improves the overall handling, acceleration and efficiency of a snowmobile. The snowmobile must be able to reach a high MPG rating while operating. The snowmobile is to be used on groomed trails and needs to be able to go long distances between refills. To maintain the excitement factor of riding a snowmobile, the engine must be powerful enough to maintain or be close to factory performance.

Budget Constraints

The budget with the project was composed of two different sources. A standard budget was obtained from the NDSU Mechanical Engineering Department. CSC rules allow for the recruitment of sponsors; therefore, a substantial contribution of monetary, expertise and parts were received from various sponsors. One of the events for the Clean Snowmobile Challenge is the manufacturer's suggested retail price (MSRP) event. Design considerations must validate additional cost associated with installing new components to a factory snowmobile chassis. The final design must emulate a feasible solution for production snowmobiles. The cost to the consumer should be less than $15,000.

Environmental Constraints

The clean snowmobile challenge is based on making snowmobiles that can run cleaner, quieter and more efficiently. Emissions are a large component of the environmental constraints. Emissions results come from engine in-service and lab emissions tests which account for a total of 21% of the overall points. This testing measures the output of Nitrous Oxides (NOx), Carbon Monoxide (CO), Hydrocarbons (HC) and particulate matter (soot); therefore, these emissions components must be minimized in addition to minimizing brake specific fuel consumption. Another large portion of the environmental constraint is noise pollution. This section accounts for 20% of the possible points awarded from objective and subjective noise performance. Since a standard stock snowmobile has a noise output of approximately 79 decibels, the constraint will be set to 79dB or less.

There must be no leaking fluid of any kind such as engine oil, diesel fuel or engine coolant. These fluids can lead to ground pollution that can be detrimental to the surrounding environment. Additionally, a team could be disqualified from competition if leaks are found. The “clean” aspect of this competition applies to all areas of the snowmobile, not just the engine. All fluid lines, pans, containers and filters will be checked multiple times for fitment to ensure there are no fluid leaks.

Safety Constraints

With the safety of the riders involved and the people that may be near the snowmobile, there are certain safety constraints that must be followed. The first of these safety constraints is that two fire extinguishers must be with the team at all times. One of these extinguishers must be mounted to the snowmobile and kept throughout the competition whereas the other must be brought to inspections with its mount attached. Another safety feature that needs to be in place is a dead-man’s tether with a maximum length of 5 feet. When the tether is pulled, the power is cut to the engine eliminating a runaway event. The final safety features are fuel and electric shut offs.

Snowmobile Designs

Engine Selection

The design of a snowmobile that can be deemed acceptable for use within environmentally sensitive areas focuses on two primary factors—reduced emissions and improved efficiency. As the primary focus on cleaner and more fuel efficient vehicles has recently pertained to the use of hybrid systems, internal combustion engines still remain the most practical implementation in recreational vehicles. Recently, the use of cleaner burning bio based flex fuel has been an improved alternative to the conventional fuel.

As the CSC rules outline, acceptable fuels include ethanol (E40 to E85) or biodiesel (B00 to B9). Both flex fuel types effectively reduce emission output by volume; however, biodiesel has an average energy density of 121,000 BTUs per gallon versus ethanol's 75,000 BTUs per gallon. Considering equivalent energy, one gallon of biodiesel could be equated to 2.25 gallons of ethanol [9].

It was decided that a diesel engine would be most suitable for reducing emissions while obtaining maximum performance. The diesel engine has the highest thermal efficiency of any internal combustion engine due to its high compression ratio. Better fuel economy can be obtained due to thermal efficiencies of up to 50%.

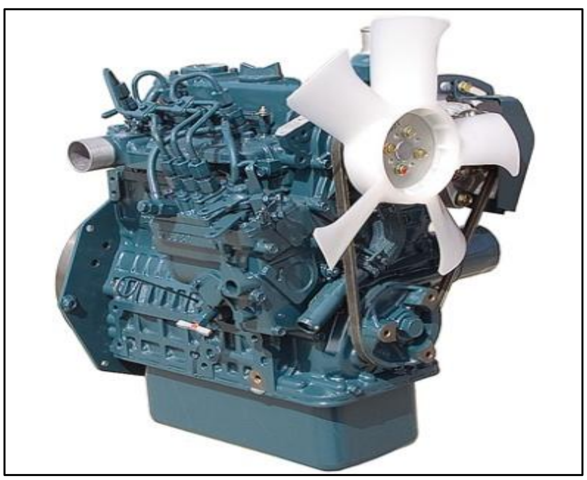

Figure 1. Kubota D902 Diesel Engine

A Kubota D902 0.898L three cylinder mechanically injected engine ***(Figure 1)*** was chosen for its compact size and power capabilities listed at 24.8 hp and 40 lbf-ft [8]. This engine also complies with Tier 4 Federal Emissions Standards, the most recent off-road restrictions.

A technology that was tested for use in a Kubota D902 engine was a common rail fuel injection system ***(Figure 2)***.

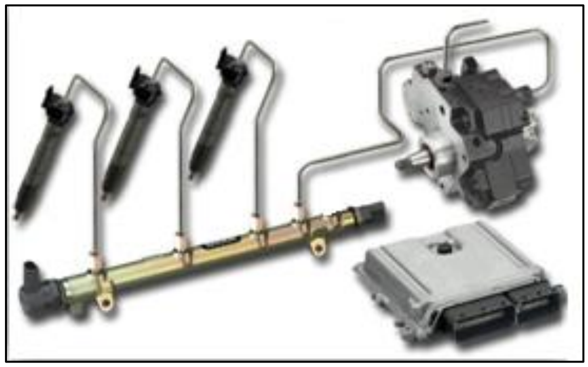

Figure 2. Common Rail Injection System

A common rail engine utilizes an Electronic Control Unit (ECU) which controls timing and quantity of fuel that is directly injected into each cylinder. This control allows for optimized control of the fuel reducing explosiveness (noise) and vibration that results from each firing. Another advantage with using an ECU is the ability to add more fuel to the engine under cold start conditions improving reliability. Pressures within the common rail can reach 29 kpsi causing better atomization of fuel. All these factors contribute to better fuel economy, a key area of focus in competition testing.

As testing progressed, extreme engine knock resulted due to crankshaft sensor malfunction, therefore a proposed deadline had been reached. Because engine reliability is crucial to the overall success of snowmobile performance, it was determined that a mechanically fuel injected engine was the best design choice at this time.

Fuel Injection System

The injection pump on the Kubota D902 is a rotary, inline cam and plunger style pump that is mounted to the side of the engine block. The camshaft that drives the injection pump actuates plungers inside the pump; these plungers compress fuel to a pressure above 1800 PSI. The high pressure pulses produce flow through steel lines to injectors which then injects fuel into a pre-chamber where ignition is initiated. Finally the combustion process continues into the cylinders. The injectors are the objects shown on top of the motor with red caps and the injection pump is on the side of the engine also with red caps (***Figure 3***).

Figure 3. Kubota engine with rebuilt injectors and injection pump.

The injection pump and injectors were taken to Midland Diesel Injection Service of Fargo, ND to be cleaned and tested in order to ensure proper operation. The injectors are from a larger 4 cylinder Kubota diesel engine and allow for a greater volume of fuel to be used, increasing the total power output of the engine. To aid these larger injectors, the fuel injection pump was also reworked by Midland Diesel Injection Service to supply more fuel and at a higher pressure. The higher pressure allows for greater atomization of the fuel used, which will lead to a more complete burn of the fuel, thus increasing the efficiency of the engine as well as power.

The previous fuel system running at 10 psi consisted of an in-tank fuel pump that fed into a fuel pressure regulator. This system also included a fuel filter which lead to a stock mechanical engine mounted fuel pump. Finally, the fuel was fed to the injection pump. Due to its complexity, this system encountered issues when operating below a half tank of diesel fuel. The engine was not able to exceed 3000 RPM, which drastically reduced the power during operation. Upon further investigation, it was believed that there was air entering the in-tank mounted fuel pump through a pickup fitting. This fitting was repaired and new pickup lines were installed to ensure there was no air introduced into the fuel system. When issues persisted, the in-tank pump and the fuel pressure regulator were removed. The fuel pressure was found to be only 3 psi with the use of the mechanical pump.

A redesigned fuel system utilized a single inline fuel pump producing 10-15 psi. This pump pulls fuel from the tank, and pushes fuel to the filter. Fuel is then fed directly to the injection pump. A fuel pressure gauge was installed after the fuel filter to continually monitor the fuel pressure. During operation the working pressure was found to be 7-10 psi.

The engine was tested using a Dynomite water inertia dynamometer to provide engine load and record the resulting data. The engine was tested in its original naturally aspirated form. The stock factory power and torque rating for the D902 Kubota are 24.8 hp and 40.0 lbf-ft, respectively [8]. With testing conducted on the engine dynamometer, the peak power had increased to 30.3 hp at 3224 rpm and 52.0 lbf-ft of torque at 2235 rpm. This gave the engine a 22.2% increase in power and 30.0% in torque.

These modifications fall under both the competition and team constraints. Increasing the power was done in an effort to improve the performance of the factory engine. With the larger injectors able to inject more fuel, there will be less need to run the snowmobile at full throttle, which will improve the overall fuel economy. This modification also follows both the competition constraints and that of the team's.

Forced Induction

The stock intake configuration of the D902 Kubota did not include any form of forced induction. In order to increase the efficiency of the motor while increasing total power output, forced induction was added. The previous engine system was configured with a single HK12 Garret turbocharger, which required repair and rebuilding. Initially the redesign of the turbo system incorporated the utilization of a sequential turbocharger; however, time and space restraints only allowed for the use of a single turbocharger system. The time required to source, tune, test and fit the sequential turbo system would have pushed the snowmobile completion date beyond the competition deadline.

Testing was conducted on the stock engine configuration in order to source a new turbo that was a match to the required operating conditions. Recorded data included: volumetric airflow rate into the engine, the fuel consumption rate, exhaust gas temperatures, ambient air temperature, horsepower, and torque output. This data was entered into a turbo compressor calculation spread sheet that was provided by Mike Ruth of Cummins Inc. to find the pressure ratio of the engine at various RPM levels ***(Appendix 1).*** Pressure ratio values were compared to various turbocharger operating ranges to find a turbo that would function properly with this application ***(Figure 4).***

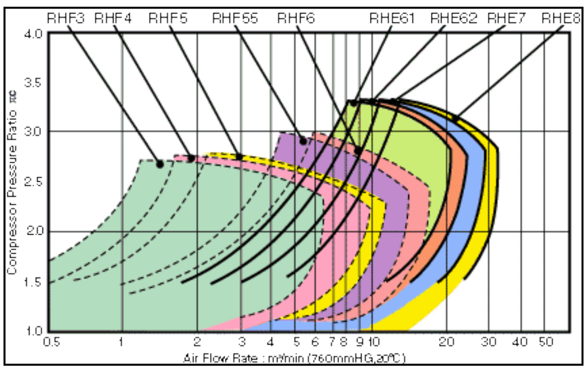

Figure 4. Turbo Operating Range

Figure 5. IHI RHF3 Turbocharger

This was in the effort to allow the engine to have a greater volumetric efficiency. With greater efficiency, the engine has a more complete combustion event and lower the overall emissions produced. Upon completion of testing and consulting with Mike Ruth, a IHI RHF3 turbocharger (***Figure 5***) was selected based on its performance curve.

Once the turbocharger had been sourced and installed onto the engine, testing was again conducted to find the performance enhancements that the turbocharger had made. As stated earlier, prior to the turbo install the horsepower was 30.3 HP and 52.0 lbf-ft of torque with just fuel modifications. After the turbocharger was installed, with no exhaust after treatment, the peak horsepower and torque had increased to 52.7 hp at 3652 rpm and 78.9 lbf-ft at 3311 rpm. This was an increase of 73.5 % horsepower and 51.79% torque over the fuel modification horsepower and torque. Over all this accounts for a total increase of 112.5% horsepower and 97.2% torque ***(Appendix 2).***

Several areas of the competition are improved through use of forced induction. One benefit included lowering exhaust emissions, 21% of the overall competition points. This induction configuration also improves the efficiency of the motor, thus improving fuel economy; the fuel economy and endurance accounts for 14% of total points in the competition. The turbocharger can minimize exhaust sounds coming from the tailpipe accounting for 20% of the competition points.

Intercooler / Radiator Placement

The application of a turbocharger produces increased specific power in an engine system. Resulting factors with such a setup are higher combustion and exhaust temperatures. The exhaust exiting the engine passes through the turbocharger and heats the air flowing through the compression portion of the turbocharger. Without the use of an intercooler high temperature intake air produces increased temperatures inside the engine and pre-detonation could occur. This would cause over pressurization in the cylinders damaging the engine block. This hot air entering the combustion chamber has a higher density than it would have if it were cooler air. This would cause a significant decrease in performance that would have instead been gained by the use of the turbocharger.

Utilizing an intercooler eliminates these issues by cooling off the compressed intake charge by the use of air to air convection (***Figure 6***). The air passes through the intercooler after being heated in the compressor section of the turbocharger. The intercooler is positioned on the front end of the snowmobile to allow for the maximum atmospheric air flow to pass through the intercooler. This will cause the compressed intake charge to cool and drop in pressure prior to entering the combustion chamber thus reducing the combustion and exhaust temperatures.

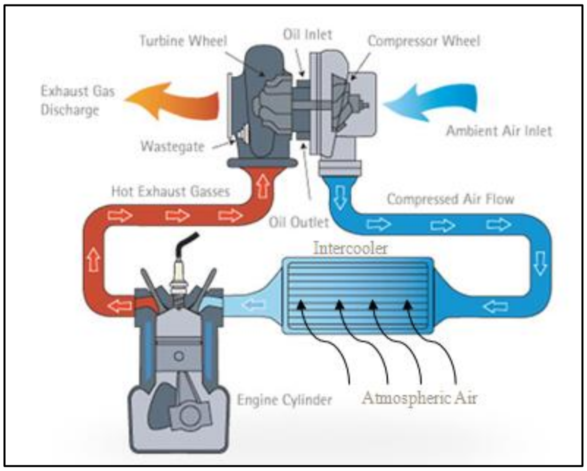

Figure 6. Intake Air Flow Diagram

The intercooler that was used in the 2012 design was a one-off intercooler. An intercooler core was used and side aluminum tanks were welded on. The welds that were applied were not sufficient due the use of JB weld on portions of the aluminum weld. With the application of a turbocharger and limited space available, an efficient and structurally sound intercooler was desired. For maximum efficiency, a manufactured intercooler that is designed to cool the compressed intake air charge from a turbocharger was selected (***Figure 7***). This stock intercooler was donated to NDSU by Polaris Industries.

Figure 7. Polaris Stock Intercooler

Another pivotal part for the engine is a radiator. This is similar to the intercooler except the fluid that is cooled is engine coolant. Antifreeze circulating through the radiator is cooled by convection heat transfer by atmospheric air. This coolant is routed through the engine maintaining a reasonable operating temperature. The placement of the radiator was also changed. According to computational fluid dynamic results ***(Figure 8),*** low velocities were found directly behind the intercooler. The radiator was installed in the path of increased velocity above the intercooler.

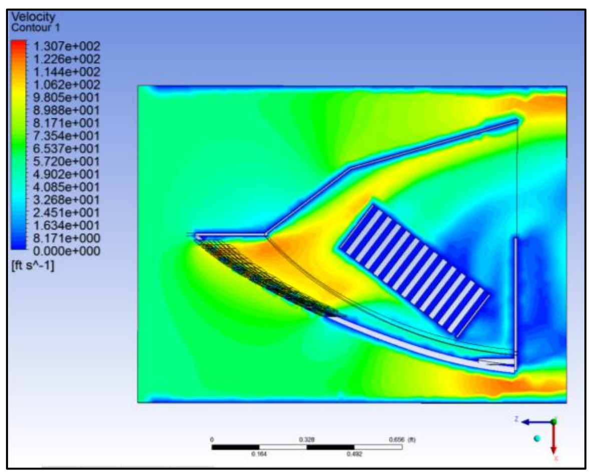

Figure 8. Entrance Velocity Profile

Due to the increase in size of the new intercooler and the placement change of the intercooler and radiator, a new front bumper was designed to accommodate available space. The material that was chosen was Aluminum 6061 T6. FEA was performed to confirm the structural rigidity (***Figure 9)***. A vertical lifting force of 750 lbf was applied using a factor of safety of 1.25. The force applied exceeds the total recorded weight of the 2012 CSC snowmobile. A factor of safety of 1.25 confirmed no failure under such loading.

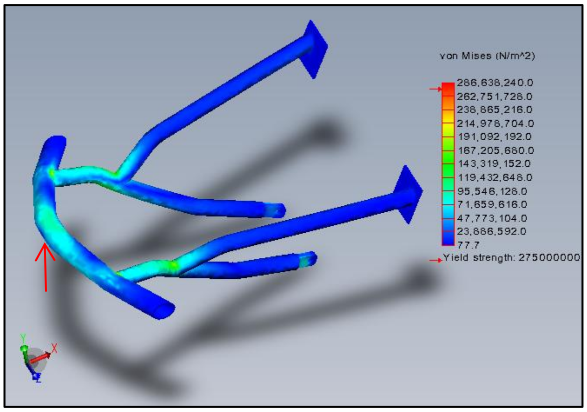

Figure 9. Von Mises Stress Analysis

Water methanol injection

Water methanol injection has been used with various types of engines. The purpose of this system is to lower combustion temperature generated, lower nitrous oxides (NOx) emission and increase performance of the engine. Water methanol injection can lower NOx production by reducing the temperature change in the intake system. Besides reducing NOx produced, water methanol injection also increases the power produced by the engine by increasing the fuel in the system through the injection of methanol. Additionally, methanol injection with its cooling effecting increases the compression ratio in the cylinder and reduce pre-ignition. The system contains an electronic control unit (ECU), electric pump, reservoir tank, and injectors ***(Figure 10)***.

The system atomizes a 50/50 mix of water and methanol into the intake as a set volume per engine RPM. Testing dictates the amount to be injected at desired RPMs or boost pressure. To achieve adequate atomization in the intake, a fuel pressure must reach 100 psi to overcome boost pressure and atomize the water methanol mixture. Since the water methanol injection occurs before the intake manifold, atomization of the water methanol mixture can occur during the intake process, eliminating the need for a complex injection system [4]. The water methanol injection system has been implemented on the sled with 1.32 gallon tank and 130cc/min nozzle. The flow rate does change depending on boost pressure and further tuning must be performed for adequate performance [5].

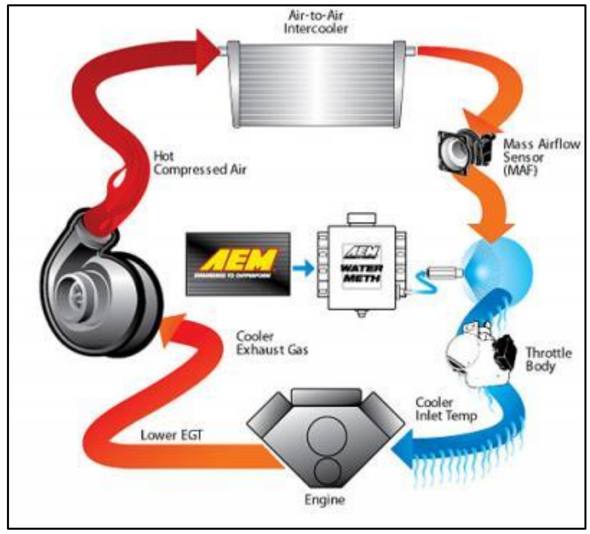

Figure 10. Water Methanol Injection System

Emission

The 2013 Clean Snowmobile Competition point break down places 25% of the total points possible on emission requirements. With such a high portion on the total points dependent on emissions, research on finding the best method possible was important. As research on emission systems was performed, it was discovered that there are three main ways to reduce emissions: filtration, reaction and prevention.

The filtration method consists of a diesel particulate filter (DPF) and a diesel oxidation catalyst (DOC). The DOC changes the chemical compositions of hydrocarbons carbon (HC) and soluble organic fraction (SOF) as seen below in equation 1, 2, 3 [7].

$$CO + 1/2O_2 \longrightarrow CO_2 \qquad (1)$$
$$[Hydrocarbons] + O_2 \longrightarrow CO_2 + H_2O \qquad (2)$$
$$[SOF] + O_2 \longrightarrow CO_2 + H_2O \qquad (3)$$

The DOC is required in every exhaust system and must be designed for. The exhaust temperature must be greater than 300°C to have 90% efficiency as desired, refer to ***Figure 11*** below.

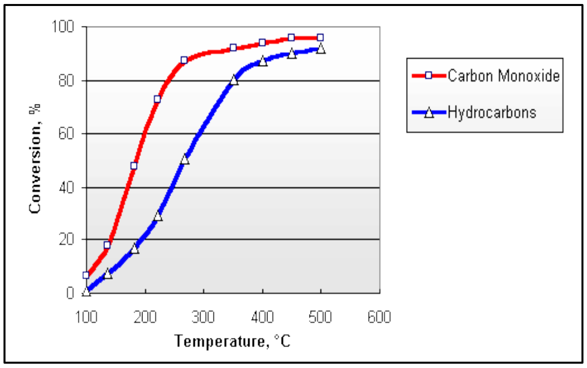

Figure 11. Temperature vs. Conversion efficiency

DOC cannot filter all the emissions therefore it must be combined with a diesel particulate filter (DPF) to filter out the unburned hydrocarbons or soot [6]. There are two types of DPF: single use or regenerative DPF. Single use DPF need to be replaced regularly, similar to an oil filter. Regenerative DPF consist of two main methods to remove or clean the DPF: passive and active regeneration. Active regeneration uses an injection of hydrocarbon with a spark ignition to burn away the soot collected. Passive regeneration uses a catalyst to react with the unburned hydrocarbons and diesel particles to produce non-harmful chemicals at temperatures greater than 300 degrees Celsius. The DPF acquired from SAE is an Emitec's PM-METALIT that uses a deep wall-flow filter. This filter needs an upstream DOC to convert NOx and carbons to H20 and oxygen [2].

The second method is reaction. This method is commonly known as selective catalyst reduction (SCR). The SCR system is most effective when used with a DPF and DOC. With the combined system it is the most effective system in use today. The SCR works by using a DEF liquid that is injected in the exhaust line to react with the NOx and produce N2 and ammonia oxide. However, there are some problems with this system which deal with the injection of DEF and operating temperatures. Snowmobile operating temperatures have to be significantly low in the subzero degree Fahrenheit range. With DEF having an average freezing point around 12 °F, a heater would be required. The amount of ammonia is also crucial to the amount of exhaust flowing in the exhaust pipes. A complex algorithm would have to be created for effective emission reduction. Therefore this system did not meet of requirement of operating temperature of -32°F hence no further research was performed on using SCR system for the snowmobile [1].

Another common system is an exhaust gas recirculation (EGR). This system works by removing some of the exhaust gases from the exhaust line, cooling the removed exhaust gases and returning the gases to the intake manifold, hence exhaust gas recirculation. This system reduces NOx production by preventing its production in the first place. It raises intake temperature and lowers combustion temperatures resulting in lower NOx produced. There are various ways to utilize an EGR system with valve timing and EGR valve. With combining exhaust gases with intake gases, a decreased change in temperature of intake gases and combustion gases results. This lowers fuel consumption resulting in lower NOx and increased fuel economy. Besides lowering the amount of NOx produced and an increase in fuel economy, the EGR system has significant negatives. The EGR system reduces power by hindering the effects of the water methanol injection and intercooler due reduction in fuel consumption and lower combustion temperatures. The acceptable amounts of emission production change with a direct relationship with horsepower generated based on competition standards. By hindering the power of the engine, a higher standard for acceptable emission production is induced [3].

At first the only knowledge on the emission was that it failed the 2012 competition, As a result with quick examination of the three types of methods and a design to utilize multiple methods was developed. Since two out of three methods passed the criteria, the methods considered were the EGR and filtration method. The SCR system did not meet the competition constraints, because it could not operate in a subzero climate. As further research was performed and more knowledge had been gained on what went wrong at competition. It was determined that the oil leak in the turbo caused the emission failure with an over production of soot. Therefore the EGR system would have little effect on the emission and was removed from the design.

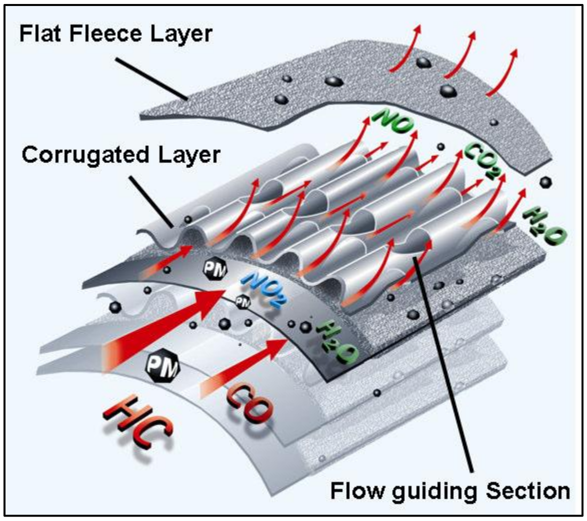

Figure 12. Emitec PM-METALIT® Filtration Technology

The filtration equipment selected for use is the Emitec partial flow DPF combined with an upstream DOC. This method maintains most of the particulate conversion efficiency (40-60%). As seen in ***Figure 12,*** HC, PM and NO2 are reduced the C02, H20 and NO.

As engine testing was performed, emissions were tested using a sniffer capable of measuring %O2 %CO, %CO2, PM-HC*100, PM-NO and PM-NO2. The readings of the sniffer are tabulated below in ***Table 1***.

Table 1. Emission Test Results

Environ-ment	O2 %	CO %	CO2 %	PM HC *100	PM NO	PM NO2
No Emission	20.9	0	0	0	0	0
Running Sled	19.3	.017	2.33	.333	184	71.6

The recorded readings verify that the emission system was working properly and the system reduces the pollutants being produced by the engine. Besides reducing pollutants, another item considered was the back pressure generated by the filtration equipment. Dynamometer testing was performed comparing the engine performance with and without the exhaust system. The peak horsepower without the exhaust system was 52.7 hp compared to 51.2 hp with the exhaust system. The engine performance has decreased by 1 hp, therefore has little restriction on the engines performance. After engine testing and emission testing, the filtration method was found to meet the requirements of the competition and was fully implemented on the snowmobile.

Oil System

Designing for optimal handling, custom engine mounts were utilized from the 2012 design lowering the center of gravity of the snowmobile. A modified oil pan had been constructed in 2012 to address clearance constraints by lowering the engine. Field testing confirmed an oil leak resulting from a faulty seal between the oil pan and engine block. A new oil pan was designed ***(Figure 13)*** utilizing a stock Kubota oil pan gasket flange to ensure a leak free seal.

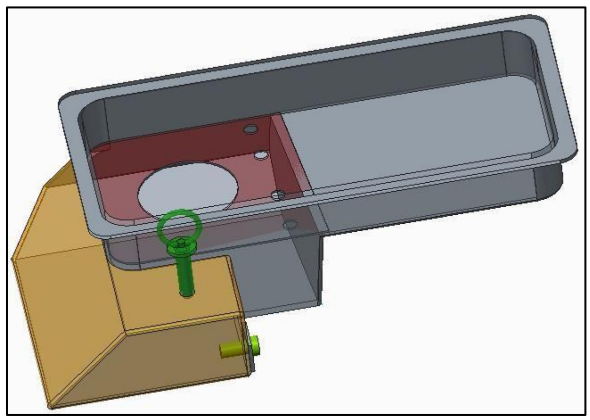

Figure 13. Modified oil pan design

The stock oil pan for a Kubota D902 has a capacity of four quarts. This volume is necessary for the intended use of this engine—heavy industrial use. By modifying the stock oil pan, a reduction in oil capacity was to be expected. The design of a wing on the pan increased capacity from 1.44 quarts to 2.35 quarts. This represents a 63.9% increase in volume compared to the 2012 design. Benefits of this higher capacity include longer intervals between oil changes and a reduced oil temperature. As seen in ***Figure 13***, a tray was implemented over the oil well to prevent oil from leaving the well during aggressive riding causing starvation.

While improving the oil performance, overall maintainability of the oil system was a key area of design. An addition to the oil pan was a dipstick for accurate oil level and routine maintenance. The current placement of the engine does not allow for removal of the oil filter when the engine is in the chassis. This requires the removal of the engine for every oil change. A remote oil filter ***(Figure 14)*** was installed in a more accessible location. The system is

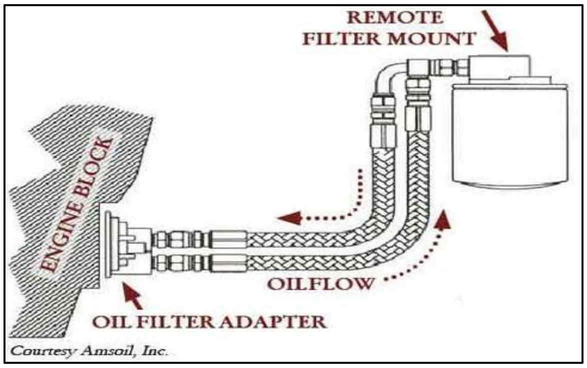

Figure 14. Remote Oil Filter System

composed of an engine block mount, two oil lines, and an oil filter. The ability to perform routine maintenance on the snowmobile outweighed the minimal initial cost associated with installing a remote oil filter.

Steering System

When the initial plan was to utilize the common rail engine, a test fit of the new fuel rail system and fuel pump was performed to check how these components fit. This test fit showed that there was interference between the fuel rail and the steering column. Being the fuel delivery system is a pivotal part of the operation of the engine, damage to the fuel rail had to be avoided. The idea came about to utilize a hydraulic steering system.

This system would use a hydraulic actuator mounted between two thrust bearings, approximately three inches apart, to eliminate the axial and radial movement. This actuator would be the driving force for pushing the fluid through hydraulic lines to a double ended hydraulic piston. This piston would then be connected to the tie rods attached to the skis. There would be no pump powered from the engine, so the whole system would be operated using the power of the driver.

The major benefit by utilizing this system is the availability of more space in the engine bay by eliminating the steering shaft. Also the hydraulic lines are flexible and can be routed anywhere on the snowmobile. Although there are some benefits we would gain using this hydraulic system, we cannot justify its use. The system all together would cost upwards of $500 including the actuator, hydraulic cylinder and lines, as well as bearings and mounting hardware.

The decision was then made to use the mechanically injected engine and revert back to using the mechanical steering column. It was discovered that there was some movement in the axial direction of the steering column and this movement could displace the column from the joint at the base of the steering shaft. A snap ring was placed over the shaft securing it in place. It was believed, that at points of a snowmobile ride, there would be large forces being acted upon this steering column. To eliminate the chance of the snap ring breaking and rendering the steering useless, a clamp was tightened around the shaft just under the steering tower. This results in no movement in the axial direction of the steering column and solidifies the shaft in place.

Suspension/ Handling

Overall static weight was a significant design consideration in this project. Added weight affects the handling, acceleration, economy and over performance of a snowmobile. One way to improve handling was the use of a better suspension design. Consulting with design engineers from Polaris industries, the application of lighter Holtz front suspension, lighter track, and wider Pro Steer skis would increase overall performance and handling of the Turbo IQ LX chassis. The new front suspension has a total weight loss of 11 lbf. Ryde FX Air 2.0 shocks were incorporated in the new design for their durably qualities. Reducing weight with a lighter track reduces rotational mass improving efficiency. The use of wider skis adequately supports a heavier snowmobile increases handling.

Noise Reduction

As a part of the Clean Snowmobile Challenge Competition, noise is worth about 20% of the total points awarded. The main contributing factors to noise generation are vibration noise and engine system noise. To decrease the vibration noise in the system, lizard skin had been applied on the chassis. Lizard skin is a sound damping coating that was used to reduce vibration noises in the chassis in this design. To increase sound damping in the engine area, heat resistant foam was applied under the hood and side skirts to absorb sound generated in the engine compartment. Another sound damping device is the use of a muffler. The muffler is designed to absorb and direct the engine sound into the sound damped chassis. This causes the sound to be absorbed by the snow and the sidewall of the chassis. During field testing, interference was found between track and muffler under dynamic movement of the snowmobile. With limited placement of muffler, use of a muffler was deemed unacceptable for application.

CONCLUSIONS

In the past North Dakota State University (NDSU) has proven to that the implantation of a small turbo diesel in a snowmobile a reasonable option for a clean, quiet and efficient vehicle.

This year the NDSU team has improved the snowmobile engine performance by incorporating a forced induction system, fuel system and water methanol injection system. Emission requirements will be met using an exhaust filtration method injunction with water methanol injection. When all the systems are put together the snowmobile produces 51.4 hp with 76.4 lbf-ft. Even though the horsepower is lower than the stock snowmobile, the increase in torque will be ideal for a utility snowmobile that is required for work. As a result of this year's modification, the 2013 NDSU clean snowmobile would be an ideal platform to be put into service.

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DEFINITIONS/ABBREVIATIONS

B0	Fuel Blend With 0% Biodiesel
B9	Fuel Blend With 9% Biodiesel
BTU	British Thermal Units
CC	Cubic Centimeters
CO	Carbon Monoxide
CSC	Clean Snowmobile Challenge
DB	Decibel
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
E40	Fuel Blend Of Up To 40% Ethanol
E85	Fuel Blend Of Up To 85% Ethanol
ECU	Electronic Control Unit
FEA	Finite Element Analysis
HC	Hydrocarbon
HP	Horsepower
MPG	Miles Per Gallon
NOx	Nitrous Oxide
PSI	Pressure Per Square Inch
RPM	Revolutions Per Minute
SAE	Society Of Automotive Engineers

APPENDIX 1. Pressure Ratio Calculation Spread sheet

A/F	Intake O2	Vol Eff	RPM	Disp	IMT	Mdot fuel	Mdot air	O2 stack	Mdot EGR	Mdot Stack	Mdot charge	EGR	Pint
[none]	[%]	[none]	[rpm]	[L]	[deg F]	[lb/hr]	[lb/min]	[%]	[lb/min]	[lb/min]	[lb/min]	[%]	[bar abs]
24	20.79	0.9	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	2.93
24	20.79	0.88	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.00
24	20.79	0.87	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.04
24	20.79	0.86	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.07
24	20.79	0.85	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.11
24	20.79	0.84	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.14
24	20.79	0.83	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.18
24	20.79	0.82	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.22
24	20.79	0.81	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.26
24	20.79	0.8	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.30
24	20.79	0.79	3000	0.98	150	22	8.80	8.23	0.00	9.17	8.80	0.00	3.34

APPENDIX 2. Horsepower versus Torque with No Exhaust Atmosphere