Re-Engineering a 2011 Polaris Rush Two Stroke for the Clean Snowmobile Challenge 2015

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ABSTRACT

Northern Illinois University's Clean Snowmobile team will compete with a re-engineered 2011 Polaris Rush 600 in the 2015 Clean Snowmobile Challenge. The snowmobile will retain its factory equipped two stroke engine. The team has met the competition objectives which are to maintain or increase the snowmobile's performance while improving its exhaust noise and emissions. The stock Polaris ECU was supplemented with an add-on fuel controller to allow for the Isobutanol conversion. The fuel delivery system was also modified in order to make the engine tuning process more simple. These modifications were done with user friendliness, cost effectiveness, and clean emissions in mind. The snowmobile was setup to utilize already available consumer parts; this makes it possible for the average snowmobiler to take advantage of our improvements. When we visited the Illinois Association of Snowmobile Clubs, the snowmobile was found to be an exciting option for recreational riders and performance oriented riders as well.

INTRODUCTION

Northern Illinois' clean snowmobile team members have been a part of the snowmobiling community for the vast majority of their lives. Our members have grown up in a generation where the negative impacts of pollution have been brought to the public eye and become a major focus of the national government. The fact that many snowmobiles in use today produce a high amount of chemical pollution has given rise to conversation, debate, and political action in many parts of the world. One case is described in a paper by James E. McCarthy, where he outlines the EPA standards for emissions that were recently applied to snowmobiles [1]. Often snowmobiling takes place in and around environmentally sensitive areas, such as Yellow Stone National Park. By reducing the chemical and sound emissions of snowmobiles, we can reduce the negative footprint that snowmobiling creates. This impact on the environment has created new objectives for college students [2]. Our team members are motivated to improve emissions and fuel economy so that future generations can grow up enjoying the exciting sport that is snowmobiling.

The team began with a 2011 Polaris rush 600 that met factory specifications. The first goal the team established was to create a system to make the snowmobile perform on the new Isobutanol fuel blend. This was accomplished by changing the four injector system to a two injector system, which also made the fuel system easier to maintain. We also decided to keep the stock two stroke engine in our snowmobile. When we visited the Illinois Association of Snowmobile Clubs' annual convention in October, we had the chance to network with hundreds of snowmobilers of all age groups and experience levels. Many people loved that we were taking the approach of cleaning up the two-stroke engine. Most of the riders we talked to expressed that they preferred the performance of the two-stroke engine in their personal snowmobiles (rather than four-stroke), leading us to the conclusion that the majority of the snowmobiles on the trails contained two stroke engines. After we did some research, we found a table from Polaris that justified our assumptions [3]. That is why we wanted to improve the emissions, fuel economy, and sound of the two stroke engine.

The team has the goal of proving that a traditional two stroke engine is a viable option for this competition. In order to achieve this goal, we focused mainly on tuning the snowmobile in order to clean up the emissions and improve the fuel consumption through all areas of the power band. In order to improve the overall safety of the machine, we also focused on improving the traction and braking systems. According to our contacts at Polaris, the improvements we have made to our snowmobile can be an example for a vast majority of the snowmobiling community. When considering our design changes for the competition, we were trying to keep the average snowmobiler in mind. Since roughly 76% of the snowmobiles on the trail have two stroke engines [3], many of the changes we have made could be made in the shops of thousands of snowmobilers, effectively reducing emissions for thousands of snowmobiles that are on the trails right now.

Team Objectives

Reduce Exhaust Emissions

The Northern Illinois University (NIU) team has an objective of lowering the exhaust emissions to a level that can compete with four stroke engines. We view this as the most important objective on our list, due to the environmental issues that come from air pollution. A five mode test will be conducted to verify that each snowmobile complies with 5-mode test cycle adapted by the EPA in 2002. Table 1 clearly identifies each mode and corresponding categories.

Table 1:5-mode emission test cycle

Mode	1	2	3	4	5
Speed %	100	85	75	65	Idle
Torque %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Test results will show the quantities of CO (carbon monoxide), HC (hydrocarbons), and NOx (nitrogen oxides). HC+NOx are not allowed to be greater than 90 g/KW-hr and CO must be lower than 275 g/Kw-hr [4].

$$E = \left[1- \frac{(HC+NO_x)-15}{150}\right]*100 + \left[1- \left(\frac{CO}{400}\right)\right]*100 \geq 100 \quad (1)$$

The quantities of each are used in the formula (1) to calculate the team's emission number, where the emission number (E) must exceed 100. The main areas of concern with the two stroke combustion style are the carbon monoxide and particulate matter. Two strokes were though to contribute 15% to all mobile source hydrocarbon emissions and 9% of all mobile source carbon monoxide emissions. [5] The reduction of harmful hydrocarbons can be achieved with a decrease in oil consumption. The drawback to lowering the amount of oil that is injected into the engine is that the engine can suffer from an increase in friction. This internal friction can generate unwanted wear and heat, neither of which are good for the longevity of the engine.

Fuel Economy

In addition to the emission test, the fuel economy and endurance of the snowmobile is an important team objective. The team's goal has been to make a system that can use Isobutanol blended gasoline. This blend ranges from a 16% to 32% mixture. This change in fuel requires a change in fuel mapping, which allows for a change in the fuel economy of the snowmobile. This year's major change was to add onto the factory ECU to allow adjustments to be made to the timing and fuel maps. This allowed us to manage the air to fuel ratio in order to keep the engine as clean as possible through all modes of our testing.

Each team will compete in an endurance event that will require the snowmobile to operate on a groomed trail for 100 miles. Every snowmobile will follow and maintain progress of the assigned trail judge. The trail judge can also disqualify a team from the event if the snowmobile does not maintain the steady pace of up to 45 mph[4]. Since this speed range is a key part of the fuel economy test, we have tuned our snowmobile to be as efficient as possible within the RPM range that is required to get up to and maintain that speed while still maintaining a high level of performance.

Performance Characteristics

On top of producing a snowmobile that is better for the environment, teams are challenged with the objective of retaining or improving upon the performance characteristics. These characteristics include power, control, and handling. We chose our snowmobile because it already has excellent performance. With our conversion to isobutanol and our engine tuning, we were able to maintain the outstanding performance of the 2011 Polaris Rush 600. Since we are retaining the two stroke engine, the snowmobile has instant power and acceleration that is far superior to a four stroke engine of the same size. By adding the Hayes Trail Trac system we were able to improve the control and handling of the snowmobile. The system is used to control the brake to keep the track from sliding when the brake is applied. Instead, it applies the brake in a pulsing manner that keeps it from sliding out of control.

Conversion to Isobutanol

The Clean Snowmobile Challenge brings different and new engineering objective each year. This year's challenge is to convert a snowmobile engine to run on an Isobutanol.

Background Information on Isobutanol

Isobutanol is one of the newest chemicals in the second generation of biofuels. This new chemical's relatively high energy density, 98% of gasoline, [6] is very promising since ethanol only had about 67% the energy density of gasoline. That allowed us to not have to worry about losing power so we could focus on cleaning the emissions. We could alter the air to fuel ratio without having to worry about the need to inject extra fuel to recover the loss in power. As of right now the production of Isobutanol is growing rapidly as the tests are proving that it possibly a better solution then ethanol. We plan to prove that isobutanol can be used to clean the emissions of a two stroke engine.

The chemical composition of gasoline is C_8H_{18}. This means for the chemical reaction you need to add a lot of oxygen. The chemical composition of Isobutanol is $C_4H_{10}O$. This means when Isobutanol is used in a chemical reaction less hydrocarbons are produced. This makes the fuel additive more environmentally friendly. When burned, Isobutanol emits tailpipe emissions which contain far less climate altering greenhouse gases than unleaded gas.

Isobutanol is produced from sugar from farm waste which includes corn, wheat, wood, etc. This is a step up from ethanol because it could only be produced from corn. Then a biocatalyst is used, followed by a separator. This produces Isobutanol and/or renewable hydrocarbons. [7]

Isobutanol Conversion in Snowmobiles

Transitioning from running a snowmobile off of gasoline to making it burn a mixture of Isobutanol and gasoline is not an overly difficult task. Isobutanol, being a drop in substitute for other fuel additives [8], can be easily introduced into existing systems without extensive modification. Also, Isobutanol can be used in both two and four stroke snowmobile motor applications due to the fact that it will not only mix with gasoline but also the gasoline and oil mixture used to run two stroke motors. One major challenge and concern is the interaction between the isobutanol and the oil in the two stroke engine. We were concerned that the isobutanol would wash the oil off of the cylinder walls which could cause a catastrophic event.

Snowmobile Design

Snowmobile Selection

The NIU Clean Snowmobile team members met and discussed possible candidates that would allow for success in multiple categories; exhaust noise, exhaust emission, power to weight ratio, fuel efficiency and capability of running Isobutanol based fuels. The final decision was made to utilize the twin cylinder, two-stroke 599cc Polaris Rush. This snowmobile is one of many currently on the market that works well on both the trails as well as off trail riding. This model shares many parts with other current Polaris snowmobile models, which allows for a plethora of available parts. The suspension design is unique to the Rush and switchback chassis. The front suspension is a traditional a-arm style while the rear suspension is model specific.

Figure 1:*Polaris Pro-Ride*

The 2011 Polaris Rush 600cc is one of Polaris's snowmobiles that utilizes the "Pro-Ride" suspension system. This chassis offers increased rigidity for precise, intuitive handling, as seen in figure 1.

The increase in the rigidity of the chassis allows for a smoother and tighter riding snowmobile. The Rush was factory equipped with a traditional two stroke in-line twin cylinder engine. This engine runs on 89 Octane fuel with 10% ethanol or 91 Octane fuel.

The original engine used the Polaris "Clean Fire" system, as well as variable exhaust valves and a four injector fuel system. The four injector system combines both direct cylinder injectors with crankcase injectors. The crankcase injectors are used when the motor is at or below 10% throttle. These injectors allowed for slight cooling of the engine as well as providing smooth response at the lower end RPMs.
The disadvantage to this system is that there is a slight area of reduced power when the engine is transitioning between the crankcase injectors to the cylinder injectors

The motor we are running operates using the standard two cycle combustion cycle. In the case of modern snowmobiles, four-stroke engines are becoming more prominent. A four-stroke engine tends to last longer than a two-stroke and can be more reliable, however they are more expensive to make and maintain. We decided to keep the two-stroke engine that comes with our model snowmobile. Our intentions are to improve upon the current two-stroke engine and prove that it is a viable option for snowmobile manufacturers. We will accomplish this by reducing our emissions and improving our fuel economy.

The factory four injector fuel system was removed and replaced with the two injector setup that is currently installed on the newer Polaris 600 and 800 engines. The new fuel injectors have the same size and location as the original cylinder injectors. The removal of the crankcase injectors reduces the amount of oil being put into the engine and consequently ejected through the exhaust. This will help to reduce the chemical emissions from the exhaust. The two injector system also allows for simpler tuning and repair of the engine.

The factory settings are designed for either non ethanol or 10% ethanol blend. The factory ECU settings were modified with the use of a Dynojet Research Inc. Power Commander V piggyback system. This module allows for modifications to the factory ECU. An auto-tune module was also added to allow the snowmobile to adjust the fuel map based on the air fuel ratio read from the wideband oxygen sensor. The advantage of this additional system is that it adjusts the mapping based on either performance or efficiency settings. The sensor was placed in the expansion chamber of the exhaust. The location was chosen to lower the possibility of unburnt oil contaminating the sensor. The location is also far enough away from the engine that the scavenging effect would not affect the readings.

Braking System Modification

The braking system on the snowmobile was replaced with a Hayes Trail Trac 1.0 system. The original system was a standard hydraulic disk brake system. The system was comprised of a standard single piston caliper controlled by a lever and master cylinder combination. The Trail Trac system contains the same components but adds a hydraulic control unit, electronic control unit, and speed sensor. The system operates by controlling the brake force that is applied through the use of a hydraulic solenoid that is placed into the brake line. The system reads the track speed and prevents the brakes from locking and stopping the track. This not only allows for a more controlled stop, but also reduced stopping distance on most surfaces.

Testing

Dynamometer Runs

In order to accommodate for the requirements of CSC 2015, the team placed the engine under a variable load to simulate different riding conditions; as well as to check any performance changes after modifications were implemented. The test was performed with a Land and Sea nine inch toroidal flow water break dynamometer. The dynamometer allows simulation of a real world environment by placing variable loads on the engine while simultaneously monitoring the internal and external diagnostics of the snowmobile. The team is able to monitor rpm, horsepower, torque, exhaust gas temp, air intake flow, air/fuel ratio as well as all of the factory parameters the snowmobile measured.

Exhaust Emission Testing and Analysis

Emissions of a snowmobile are quite high in reference to a typical automobile driven on the road. Due to this, emissions of snowmobiles have been under a lot of scrutiny. For cleaner air and to better our environment, snowmobile emissions have been regulated by the government in recent years. The team focused on reducing the exhaust emissions of the two stroke engine by running synthetic blend oil, switching the fuel over to the iso-gasoline blend, and by refining the tuning to reduce overly rich sections in the original fuel mapping. If the engine can be kept in an ideal stoichiometric air fuel ratio, the engine will be producing its highest power with the least emissions. The stoichiometric ratio is the mass ratio of air to fuel. Our goal air fuel ratio varies at different RPMs and throttle ranges, but our average air to fuel ratio target was 14. The tuning of the engine was designed to eliminate areas where the engine would have excessive amounts of fuel being used to reduce the amount of unburnt fuel in the exhaust stream. The areas of the fuel map that required adjustment where the 25-60% throttle and the W.O.T. (wide open throttle). The factory fuel mapping was set to have additional fuel in these locations to prevent the excessive heat generation from a lean fuel burn. Altering these values will also increase the engines fuel economy.

The NIU Clean Snowmobile Team has access to a Nova five gas exhaust analyzer, pictured in appendix. During the dynamometer runs, the team was able to measure the exhaust gas content of the snowmobile. The exhaust gas readings were taken while the motor was placed under the EPA Five Mode test. The emissions were collected every 15 seconds, which was the fastest time the computer software was capable of logging.

The engine was tested running on 93 octane ethanol free fuel. The values that were collected from the snowmobile were taken from a test port placed in an exhaust pipe extension. The exhaust extension was designed to meet the rules for the emissions testing equipment.

Figure 2: Emissions test pipe and probe

The probe was placed "seven diameters from the point in which the exhaust exits into the atmosphere is to prevent back pulses from reaching the sample probe". [4]

The sled was tested on both the conventional 93 octane gasoline and a 26% Isobutanol gasoline mixture. The emissions values from each mode were collected and average values were found for both sets of data. The resulting change in the values is show in table 2.

Table 2: Difference in emission, stock-isobutanol

%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
1.54	0.38	-2.4	-490	-28.4	-15.6
6.44	-2.08	-2.7	-2360	-76.2	10.5
2.98	-0.34	-1.44	-1004.4	-42.8	-5.05
5.68	-0.4	-3.22	-2614.4	-80.4	5.35
1.06	-0.54	-0.1	-4596	-88	0.6

The difference in the emissions from the change in fuels allowed for a reduction in CO_2, Hydrocarbons and NO. This reduction was found across all modes. The O_2 was found to increase due to the fuel mixture being a leaner burn.

Noise Emission Testing and Analysis

As it goes for most types of machinery, especially snowmobiles, sound is an unpleasant result that should be minimized. This dilemma is one of many arguments for closing snowmobile trails to the public; whether it is environmentalist concern about frightening animals, or land owners displeased with the noise pollution primarily during night hours. We attempted to reduce our sound emissions by adding sound deadening material to the body panels of our snowmobile. Sound readings were taken in accordance to the SAE J192 test. The measured decibel reading was found to be a max of 76.9 dB. The conditions for the test were such that there was no wind, temperature of 19 degree Fahrenheit, and pressure of 30.23 inHg.

Brake System Testing

In the automotive market, ABS systems are used to battle skidding while braking while in the snowmobile market, where skidding can be a major problem, no such a system has been made available until now. The Hayes Trail Trac 1.0 system acts as an ABS system would on a modern automobile. The system has its own speed sensor, separate from the factory speed sensor that monitors the speed of the track and not allowing it to completely lock up and cause a skid under hard braking conditions.

To test out this brake system we did a series of tests both pre-installation and post-installation of the Hayes Trail Trac 1.0. We tested the braking distance as well as the time of deceleration to a complete stop at each of our pre-determined speeds, see appendix. After reviewing our data from both of the tests, it can be seen that stopping distance decreased, while deceleration time increased after installing the Hayes system. The biggest gain that was observed from this test was how the snowmobile handled subjectively during the tests. After the installation of the Hayes system, during braking, the handling was substantially increased. During the pre-installation test, the snowmobile was hard to handle and would go into a skid pushing it out sideways, while during the post-installation test skidding was held to a minimum, the snowmobile was much easier to handle and did not try to push the track out from underneath the rider.

Consumer Appeal

All of the modifications on NIU's snowmobile can be done by the average snowmobiler at home with basic tools using parts available to all consumers. With rising prices in oil affecting prices at the pump, consumers are looking more toward fuel efficient engines, as well as practical alternative fuels, without having to sacrifice performance. Enthusiasts not only look for these qualities, but also for comfort, maneuverability, and a smooth-riding suspension. Snowmobile design is constantly changing. Innovative ideas are continually being used to increase both fuel efficiency and performance. Snowmobile designers are constantly attempting to maximize all of these factors to make their snowmobile the most attractive to consumers, which is exactly what the Northern Illinois University Clean Snowmobile Team has done.

The Northern Illinois University Clean Snowmobile Team has designed a snowmobile that best fits the qualities that are highly sought after when enthusiasts consider making a purchase. Speed and maneuverability were factors when designing the team snowmobile; however these were not the only considerations. Other factors were the continuing threats of banning snowmobiling of popular snowmobile destinations, such as Yellowstone National Park, due to harmful environmental impacts related to the sport of snowmobiling. With these considerations the team was able to make a snowmobile that is both environmentally friendly and high performing by reducing the chemical emissions. The reduction in emissions shown in Table 2, will allow for snowmobiles to be allowed into conservation areas in the future.

The snowmobile was designed to provide a high performance, efficient, and user-friendly alternative to the currently available market of snowmobiles. The consumer would be able to maintain the ride-ability that current snowmobiles offer, while producing less harmful emissions and sound output. The use of pre-existing parts reduces the need for new parts to be designed or manufactured.

Safety of the Rider

When designing the snowmobile, the safety of the operator was another important consideration of the team. We utilized the factory shielding of moving components because we did not modify stock drive line. More aggressive Woody's carbides were implemented under both skis in order to improve handling and responsiveness of the snowmobile. Woody's picks were implemented on the track to help fight skidding and sliding in low traction conditions. The Hayes Trail Trac 1.0 system was installed to minimize skidding while braking and decrease braking distance.

Cost Effectiveness

The MSRP for the snowmobile designed by the Northern Illinois University team is $13,245.62

The modified 2011 600 Polaris Rush snowmobile has a couple of benefits over the compared 2015 Polaris Rush 600 Pro S snowmobile. The snowmobile we designed is less than $2,500 more expensive than the 2015 Polaris. This is a small amount of money when considering that all of these parts were bought at market value in single quantity. If a manufacturer decided to make the changes we made, they could do so at a much lower price point. A few of the most expensive modifications include the Hayes Trail Trac, The Dynojet Power Commander, and the Gold digger Traction Master studs. The Hayes Trail Trac greatly increased the control of the snowmobile during braking. The DynoJet Power Commander V is an addition to the ECU will make it possible for the modified snowmobile to be properly turned. Finally the Gold Digger Traction Master studs, these studs added to the track will increases the traction during acceleration and increases control during braking. All of the stated modifications to the snowmobile are reasonably priced and any consumer can install them at home with relative ease. The modifications have also improved the fuel economy, which will save the consumer money at the pump. Therefore, the final price of the NIU's clean snowmobile is a reasonable price for the overall quality of the snowmobile and the benefits it presents to its rider.

SUMMARY/CONCLUSIONS

Recreation Roundtable conducted a recent study on people who spent time outdoors. The results showed that these people lead "happier, healthier, and more productive lives [9]." They also were better citizens and neighbors in their community. As snowmobiling increasingly becomes more popular in future years, the effort for improved, dependable, and environmentally friendly vehicles will take manufacturers to a new level. SAE takes an additional step by challenging engineering students to perform many of these efforts.

The SAE Clean Snowmobile Team at Northern Illinois University re-engineered a snowmobile for better noise and exhaust emissions. Throughout the year prior to the competition, the team has designed, tested, and modified a snowmobile within the parameters set forth by the competition. While making these changes the team has been able to maintain the factory cost efficiency, costumer appeal, rider safety, and practicality.

One of the more important modifications made to the machine was the integration of the Dynojet Power Commander. This device allows for the easy adjustment of stock fuel mapping in conjunction with the stock ECU. This system is also relatively easy to install, so easy that the average snowmobile enthusiast can make changes to their snowmobile at home. Another strong improvement to this machine is the installation of the Hayes Trail Trac 1.0 braking system. This system emulates that of the ABS style brakes that would be found on any modern car. This braking system allows for greater safety and control of the machine during braking and makes the rider feel safer when they must brake at high speeds or in poor traction situations. This braking system restricts the brakes and track from locking up and prevents sliding during the braking process.

This snowmobile has the ability to run on alternative fuel blends. The changes made result in fewer pollutants than a standard two stroke engine as shown in Table 2. The average consumer in today's economy desires fuel efficiency in their motor driven vehicles as well as performance, this machine has satisfied both of those desires by maintaining stock performance while reducing the chemical emissions. The biggest improvement to the snowmobile is the decrease in pollution from the engine shown once again by Table 2. Our improvements can be applied to thousands of the two stroke engine snowmobiles that are on the trails right now. The improvements will allow for one to ride in even some of the most emission restrictive areas around the United States, such as Yellowstone National Park.

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APPENDIX

Pre-Install Test

Stop Distance (feet)		Run 1	Run 2	Run 3
	10 MPH	9.7	8.7	10
	30 MPH	51	55	58.5
	45 MPH	97	106	127.5
	50 MPH	135	135	

Deceleration Time (Sec)		Run 1	Run 2	Run 3
	10 MPH	1.5	1.2	1
	30 MPH	2.8	1.8	2.8
	45 MPH	3.6	3.6	3.2
	50 MPH	4.2	4.2	

Post-Install Test

Stop Distance (feet)		Run 1	Run 2	Run 3
	10 MPH	8.2	7.1	8.8
	30 MPH	46.6	43.4	36.5
	45 MPH	92	96	97
	50 MPH	126.5	117	

Deceleration Time (S		Run 1	Run 2	Run 3
	10 MPH	1.3	1.2	1.6
	30 MPH	2.9	3.3	3.5
	45 MPH	3.7	4.2	4.5
	50 MPH	4.5	4.8	

Pre-Install Test with studs

Stop Distance (feet)		Run 1	Run 2	Run 3
	6 MPH	4.6	4.3	3.3
	19 MPH	18.3	19.3	19
	28 MPH	40	44.6	48.75
	45 MPH	80		

Deceleration Time (Sec)		Run 1	Run 2	Run 3
	6 MPH	0.7	0.6	1.5
	19 MPH	1.4	1.4	1.6
	28 MPH	2	2.3	2.4
	45 MPH	3.2		

Post-Install Test with studs

Stop Distance (feet)		Run 1	Run 2	Run 3
	6 MPH	2	2.5	2
	19 MPH	21	20	19
	28 MPH	49.75	46.6	36
	45 MPH	84.5		

Deceleration Time (S		Run 1	Run 2	Run 3
	6 MPH	0.4	0.4	0.5
	19 MPH	1.5	1.4	1.6
	28 MPH	2.6	2.4	2
	45 MPH	4		

Hayes Trial track testing

Average emissions Collectd for Each Mode

	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
MODE 1	8.78	1.72	7.24	5550	88.4	25
MODE 2	8.16	3.7	6.26	7788.2	123.8	0.5
MODE 3	9.18	1.26	7.16	6950.6	107.6	14.25
MODE 4	9.88	0.78	6.96	7497.2	119.4	1.25
MODE 5	13.6	3.58	2.46	9364.2	109.4	0

MODE1	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	8.6	1.7	7.3	5132	93	21
	8.7	1.9	7.2	4555	89	19
	8.8	1.8	7.2	4199	86	19
	8.9	1.8	7.2	3993	87	20
	8.9	1.4	7.3	9871	87	21
0	8.78	1.72	7.24	5550	88.4	25

MODE2	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	8.5	3.6	6.3	8953	138	0
	8.4	3.9	6	8195	127	0
	8.1	3.8	6.2	7626	124	0
	8	3.7	6.3	7253	117	1
	7.8	3.5	6.5	6914	113	1
0	8.16	3.7	6.26	7788.2	123.8	0.5

MODE3	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	11.3	1.4	6	8541	106	5
	8.9	1.2	7.3	7096	112	10
	8.6	1.2	7.4	6618	109	13
	8.5	1.3	7.5	6339	107	14
	8.6	1.2	7.6	6159	104	15
AVG	9.18	1.26	7.16	6950.6	107.6	14.25

MODE4	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	10.9	1.3	6.1	8689	119	1
	9.6	0.7	7.1	7718	123	1
	9.5	0.7	7.2	7297	121	1
	9.8	0.5	7.2	6985	117	1
	9.6	0.7	7.2	6797	117	1
AVG	9.88	0.78	6.96	7497.2	119.4	1.25

MODE5	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	12.8	4.1	2.7	9278	107	0
	13.3	3.8	2.6	9506	107	0
	13.2	3.7	2.6	9822	108	0
	14.3	3.2	2.2	9204	112	0
	14.4	3.1	2.2	9011	113	0
AVG	13.6	3.58	2.46	9364.2	109.4	0

Two injector emissions

Average emissions Collectd for Each Mode						
	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
MODE 1	10.32	2.1	4.84	5060	60	9.4
MODE 2	14.6	1.62	3.56	5428.2	47.6	11
MODE 3	12.16	0.92	5.72	5946.2	64.8	9.2
MODE 4	15.56	0.38	3.74	4882.8	39	6.6
MODE 5	14.66	3.04	2.36	4768.2	21.4	0.6

MODE1	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	12.2	2.1	5.3	5401	67	8
	12.8	2.4	4.6	5187	62	9
	13	1.9	4.5	5036	59	10
	12.3	2	4.8	4904	58	10
	1.3	2.1	5	4772	54	10
0	10.32	2.1	4.84	5060	60	9.4

MODE2	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	15.9	2.3	2	6054	49	17
	16	1.5	3.1	6107	46	11
	13.8	1.4	4.4	5230	52	10
	13.5	1.7	4.2	4954	47	9
	13.8	1.2	4.1	4796	44	8
0	14.6	1.62	3.56	5428.2	47.6	11

MODE3	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	12.6	1.2	5	6680	83	8
	12.3	1.6	6.2	6126	64	7
	10.7	0.4	6.4	6019	61	8
	13	0.6	5.4	5575	60	10
	12.2	0.8	5.6	5331	56	13
AVG	12.16	0.92	5.72	5946.2	64.8	9.2

MODE4	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	17	1.2	1.6	4797	43	8
	18.7	0.2	3.2	4462	36	6
	12.4	0.3	6	5430	37	6
	14.5	0.1	3.9	4940	40	7
	15.2	0.1	4	4785	39	6
AVG	15.56	0.38	3.74	4882.8	39	6.6

MODE5	%O2	%CO	%CO2	PPM HC's	PPM NO	PPM NO2
	20.5	0	0	1666	15	0
	13.6	3.7	2.9	4461	10	0
	13.2	3.8	2.9	5324	16	0
	13	3.9	3	5916	29	1
	13	3.8	3	6474	37	2
AVG	14.66	3.04	2.36	4768.2	21.4	0.6

two injector Isobutanol emissions

Nova 5 Gas Analyzer