Considerations and Modifications, for the 2011 SAE Clean Snowmobile Challenge, of a 2007 Yamaha Phazer

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Abstract:

The objective of the team is to convert a stock 2007 Yamaha Phazer Mountain Lite to run efficiently and cleanly off of an ethanol fuel blend ranging from E20 to E29. Special considerations were given in the design process to reduce complexity and enhance performance, ensuring that the modifications are as close to market-driven engineering products as possible. Research was also conducted on the feasibility of utilizing a turbocharger or supercharger in order to assist in improving efficiency and emissions. Studies comparing the use of synthetic oil verses conventional oils were conducted to determine which performed more reliably at low temperatures. Additionally, the impact of using block heaters and catalytic converter heaters to reduce cold engine startup emissions were also measured. As a rookie team competing in the internal combustion category at CSC, the team is looking forward to gaining significant experience from the 2011 event.

Introduction:

In today's world, "green engineering" is a subject of increasing importance in the engineering field and throughout the world of science at large. Because of increased attention to conserving resources and environmental concerns, all new projects are being designed with these issues in mind. As a result, emphasis has been given to the idea of increasing a products useful lifespan while reducing its overall resource consumption during that life. This "green engineering" movement is spreading across all fields of engineering, including recreation vehicles.

Off road Vehicles such as snowmobiles and four-wheelers have been utilized for both recreational and occupational purposes for many years. These highly functional vehicles are capable of reaching parts of the world that are not accessible by car. However, they are also known to be quite environmentally damaging, specifically in the realm of particle emisions. This is very applicable to the countries national parks and reserves as well as other environmentally protected areas. By modifying snowmobiles to allow them to run on more environmentally friendly fuel, such as ethanol, travel by snowmobile could become much better for both the rider and the area they are riding in.

Conversion to Flex Fuel:

The first and most important task in preparing a snowmobile for the CSC was converting the engine to run on fuel containing up to 29% ethanol. This requires analyzing the fuel mixture so that the engine fuel to air ratio can be adjusted in real time to maximize efficiency and the timing of the engine must be altered to optimize performance. To do this an engine control system that can adjust these variables must be installed. For this task, the Dynojet's Power Commander III USB has been selected along with its corresponding ignition module. The Power Commander allows the fuel injection to be adjusted as much as 100%, while the ignition module allows the engine timing to be adjusted. Both of these components have been installed and did not adversely affect engine performance.

The second step in the conversion was to set up a system for measuring the ethanol content in the fuel being used at any particular time. The component chosen for this portion of the project was the Dynojet's Wideband Commander. The main mechanism for this particular controller is an oxygen sensor that is placed in the exhaust pipe.

The final step was to verify whether the fuel system was capable of delivering the extra fuel required to compensate for the lower energy density of ethanol relative to gasoline. As seen in figure 1, the energy density of the highest possible ethanol percentage is roughly 90% of pure gasoline. Therefore, even with the highest ethanol content allowed in the competition our fuel pump would only be doing about 10% more work and so it was assumed the stock fuel system could handle the increased flow rate.

Fuel Energy Densities	
Fuel Type	HHV (Btu/gal)
Ethanol	76,000
Gasoline	115,000
E20	107,200
E21	106,810
E22	106,420
E23	106,030
E24	105,640
E25	105,250
E26	104,860
E27	104,470
E28	104,080
E29	103,690

Figure 1: Calculated Fuel Energy Densities

Baseline Data:

Prior to the conversion to a flex fuel system some baseline testing was completed, figure 2.

Baseline Data				
RPMs	HC (ppm)	CO (%)	CO2 (%)	O2(%)
5000	126	0.8	3.8	14.85
6000	51	1.05	3.9	14.95
7000	53	1.8	4.5	13.2
8000	75	2.7	7.9	8.5
12500	500	5.15	3.2	20

Figure 2: Baseline Emissions Testing

Turbocharger Feasibility:

The possibility of adding a turbocharger to the snowmobile for this year's competition is one that was heavily researched since theoretically, higher efficiency could be achieved using a turbocharger since exhaust heat and pressure which would normally be wasted is instead recycled by the engine. To acquire a turbocharger we turned to Honeywell, also known as Garrett turbochargers. They have a program which will donate one free turbocharger to an SAE team so long as an adequate selection process occurs. We knew that the turbocharger we would want for our application would be small. Due to the clean snowmobile rules we are limited to 130 horsepower from our snowmobile. The stock snowmobile is capable of 81 horsepower so a marginal increase in maximum horsepower would be acceptable. The choice was quickly narrowed down to a GT12 wastegated turbocharger verses a GT15 variable nozzle turbocharger. The following data and tables represent calculations that were performed to determine the best turbocharger for our applications.

Calculated Using Equations and Info from turbobygarrett.com				
Target Horespower	Airflow Actual (lb/min)	Manifold Pressure Required (Psia)	Compressor Discharge Pressure (P2c)	Pressure Ratio (R)
20	2.42	13.07	15.07	1.10
30	3.64	16.34	18.34	1.34
40	4.85	18.68	20.68	1.51
50	6.06	20.43	22.43	1.64
60	7.27	21.79	23.79	1.74
80	9.69	26.15	28.15	2.05
100	12.12	29.71	31.71	2.31
120	14.54	32.68	34.68	2.53

Engine Displacement in^3	30.451
Estimated Volumetric Efficiency	0.95
Air Fuel Ratio A/F for E25	13.2186
Approximate BSFC lb/Hp*hr	0.55
Approximate Intake Manifold Temp (F)	150
Compressor Inlet Pressure Psia	13.7

Figure 3: Assumed and interpolated values used in calculations

naturally aspirated RPM	Airflowrate CFM	Coverted to Airflow Rate lb/min
5000	41.85	3.18
6000	50.22	3.82
7000	58.59	4.45
8000	66.96	5.09
9000	75.33	5.73
10000	83.71	6.36
11000	92.08	7.00
12000	100.45	7.63

Figure 4: Air consumption of stock naturally aspirated 499cc Yamaha Phazer engine

Figure 5: Values used and plotted on both a provided Garrett GT12 and GT15 compressor map. Compressor Maps are located in the appendix.

When the air flow and pressure ratio data for our engine is plotted on the given GT12 and GT15 compressor maps the following can be seen.

1.) The curve of our data fits nicely just right of center in the GT12's compressor map.

2.)The curve of our data sits dangerously close to the surge line on the GT15's compressor map.

This indicates that the GT15 is too large for our 499cc engine. While there are aspects of a variable nozzle turbo that are interesting it was concluded the GT15 is simply too large and we risk damaging our engine components if we use it. Since the curve of our data nicely fits the GT12 compressor map, we have concluded it would be best to use it over the GT15. Also given our desire for low engine speed performance and efficiency due to less frictional losses at lower RPMs, a smaller turbo is our natural inclination.

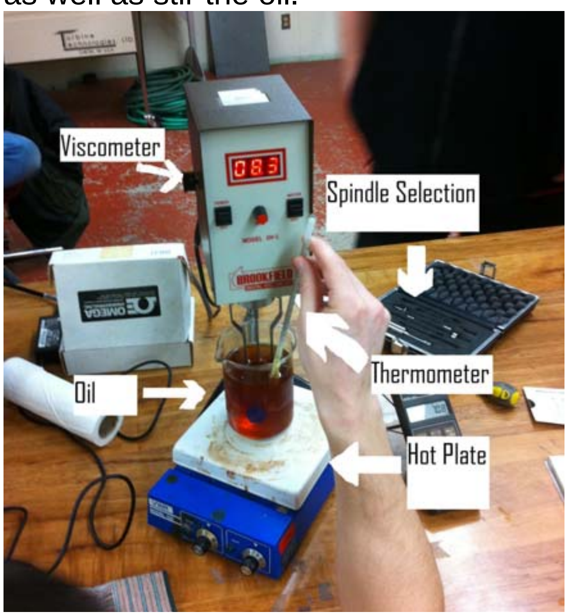
Further research was done to pick out other components of the turbocharger system. However, in this process it was determined that a turbocharger may not be a feasible possibility in this year’s competition. Due to the fuel being provided to us ranging from E20 to E29 it can be estimated that the octane rating of the fuel would be between 91 and 96. This combined with our engines stock compression ratio of 12.5:1 would make the presence of knocking nearly inevitable without lowering the compression ratio. It was finally determined that lowering the compression ratio would hurt other aspects of the competition too much to justify the occasional boost in horsepower.

Lubricant Testing:

The extreme arctic environment of Fairbanks, Alaska has motivated our team to run an experiment studying the effects of temperature on the viscosities of engine oil.

Both synthetic and conventional oils were tested to determine if the belief that synthetic oils perform better at low temperatures is true. The differences between 5W-20 and 10W-40 oils were also tested.

The apparatus, pictured below, consisted of a Brookfield DV-1 Viscometer. This used a selection of spindles which ranged in size and shape. The thinner and smoother the spindle the easier it would spin in a fluid. These were used when the samples were at very low temperatures. There were also larger spindles which were often used when the oils reached a higher temperature near the end of the experiment. A simple mercury thermometer was used to measure the temperature of the oil as well as stir the oil.



Picture 1: The apparatus used to test oil viscosities

Oil Type	Conventional 5W-20				
Temp (F)	Factor	(cp)	RPM	Spindle #	M
-28	40.0	8000	30	LV4	200
-20	41.3	8260	30	LV4	200
-15	34.0	6800	30	LV4	200
-10	25.8	5160	30	LV4	200
-5	14.2	2840	30	LV4	200
0	10.6	2120	30	LV4	200
5	8.4	1680	30	LV4	200
10	6.2	1240	30	LV4	200
25	29.7	297	30	LV2	10
30	31.0	310	30	LV2	10
35	29.0	290	30	LV2	10
45	24.9	249	30	LV2	10
55	18.7	187	30	LV2	10
65	13.4	134	30	LV2	10
75	9.9	99	30	LV2	10
85	7.6	76	30	LV2	10
100	5.3	53	31	LV2	10

Table 1: Conventional 5W-20 Oil Results

Oil Type	Synthetic 5W-20				
Temperature (F)	Factor	(cp)	RPM	Spindle #	M
-28	17.6	3520	30	LV4	200
-20	16.1	3220	30	LV4	200
-10	10.4	2080	30	LV4	200
-5	5.9	1180	30	LV4	200
0	4.9	980	30	LV4	200
5	4.2	840	30	LV4	200
20	21.2	212	30	LV2	10
25	22.6	226	30	LV2	10
30	23.1	231	30	LV2	10
35	22.8	228	30	LV2	10
40	22.6	226	30	LV2	10
45	22.3	223	30	LV2	10
50	18.4	184	30	LV2	10
55	18.2	182	30	LV2	10
60	14.5	145	30	LV2	10
65	13.4	134	30	LV2	10
70	11.8	118	31	LV2	10
75	10.8	108	30	LV2	10
80	9.1	91	30	LV2	10
85	8.6	86	30	LV2	10
90	6.9	69	30	LV2	10
95	6.2	62	30	LV2	10
100	5.6	56	30	LV2	10

Table 2: Synthetic 5W-20 Oil Results

Oil Type	Synthetic 10W-40				
Temperature (F)	Factor	(cp)	RPM	Spindle #	M
-26	94.0	18800	30	LV4	200
-20	36.0	7200	30	LV4	200
-14	26.3	5260	30	LV4	200
-10	18.6	3720	30	LV4	200
-4	14.9	2980	30	LV4	200
3	9.6	1920	30	LV4	200
32	53.2	532	30	LV2	10
37	50.2	502	30	LV2	10
43	48.2	482	30	LV2	10
48	45.6	456	30	LV2	10
52	41.3	413	30	LV2	10
57	37.4	374	30	LV2	10
63	34.0	340	30	LV2	10
67	30.5	305	30	LV2	10
72	23.7	237	30	LV2	10
77	21.3	213	30	LV2	10
82	19.1	191	31	LV2	10
87	16.4	164	30	LV2	10
92	13.5	135	30	LV2	10
96	12.1	121	30	LV2	10
100	10.9	109	30	LV2	10

Table 3: Synthetic 10W-40 Oil Results

Oil Type	Conventional 10W-40				
Temp (F)	Factor	(cp)	RPM	Spindle #	M
-26	24.7	494000	0.3	LV4	20000
-10	0.2	4000	0.3	LV4	20000
-5	42.4	848000	0.3	LV4	20000
0	44.0	4400	60	LV4	100
5	16.3	1630	60	LV4	100
10	48.9	1222.5	12	LV2	25
15	64.0	1600	12	LV2	25
19	56.0	1400	12	LV2	25
25	45.4	1135	12	LV2	25
30	39.2	980	12	LV2	25
35	35.3	882.5	12	LV2	25
40	32.2	805	12	LV2	25
45	30.2	755	12	LV2	25
50	55.2	552	30	LV2	10
57	41.6	416	30	LV2	10
60	39.8	398	30	LV2	10
65	33.5	335	30	LV2	10
72	25.2	252	30	LV2	10
75	21.2	212	30	LV2	10
82	16.6	166	30	LV2	10
87	14.3	143	30	LV2	10
95	11.1	111	30	LV2	10
100	10.2	112.2	31	LV2	11

Table 4: Conventional 10W-40 Oil Results

Plot 1: Oil Temperatures Vs. Their Viscosity at That Temperature
*Some of the outlier data points were removed to improve scale and visibility.

It can be seen from plot 1 that the 5 weight oils are less viscous. It can also be seen that the synthetic blends are also less viscous at lower temperatures. This is useful information when applied to an area such as Fairbanks where the temperature in the winter can easily reach -30 Fahrenheit. From this data, it can be concluded that it is more efficient to run synthetic oil is cold climates. This lower viscosity at low temperatures allows the oil to easily travel onto the piston and cylinder walls allowing the lubricant to effectively protect the engine after startup.

Catalytic Converter Heaters and Block Heaters:

Although not allowed in the 2011 Clean Snowmobile Challenge, the use of block, catalytic converter, battery, transmission, and oil pan heaters have proven themselves highly effective in reducing startup emissions and general wear and tear in cold climates.

The issue of global warming is also greatly increased by particulates exhausted by incomplete combustion in engines. The effects in Alaska are significant due to these particulates and greenhouse gasses capturing more of the radiation reflected by the earth's surface and the ice covering the earth. The entrapment of greenhouse gasses warms the earth which in turn melts the ice caps. Melting of the ice caps decreases the amount of radiation reflected back into space (lessening of the albedo effect), further increasing warming. As the ice caps melt, sea level rises. Alaska's ecosystems depend on the cold arctic climate makes it particularly susceptible to climate change.

Particulate matter is released by engines, especially those which are not running at a proper operating temperature. This has a visible and immediate impact on arctic environments such as Fairbanks. Ice fog as it is called in Fairbanks is actually made up of particles produced by the burning of fossil fuels in the Fairbanks North Star Bureau. These particles cause air quality issues in Fairbanks during the winter months that are so severe the EPA has mandated that the bureau deal with the issue. These issues are also exacerbated by the fact that when an engine is not at its optimal operating temperature it tends to have less complete combustion, therefore producing higher levels of carbon monoxide and particles as it warms up. Plus as an internal combustion engine runs and approaches stable operating temperature, there are extra stresses experienced by the engine as the internal parts warm up and expand at a faster rate than the outer parts.

These problems were realized early in the history of the Otto and Diesel cycle engines and people had interesting ways of dealing with them. Many people in cold climates would actually drain the engine oil at the end of the day and store it inside where it would remain warm until they were ready to use the engine the next day. Others would preheat the engine with kerosene heaters. Fortunately, today we have easy, viable, and safe ways of heating an engine before it is turned on. One way is by using block heater, an effective and underappreciated heat transfer technology that helps to greatly reduce the time it takes for an engine to reach its stable operating temperature. Other heating devices have also been proven very effective in reducing hydrocarbon, carbon monoxide and other toxic emissions from cold engine startups. Studies have shown that a block heater combined with a catalytic converter heater can reduce these types of pollutants by up to 80% in the first 10 kilometers driven by a vehicle. This is substantial considering the average length of a morning commute in Fairbanks is only 13.3 minutes.

One problem that block-heaters present is that they do use electricity to heat the engine and can cause a lot of waste if their use is not limited to only what is necessary. Research by the agricultural engineering department of the University of Saskatchewan in Canada shows that operating a block heater for longer than 4 to 5 hours is a waste of energy, as the engine temperature from then on will remain relatively unchanged. The electricity used to run a block heater comes from a local power plant; which in the case of Fairbanks, is generated from fossil fuels. The burning of these fossil fuels contributes to the problem of particulates in the air. Most people are reasonably economically minded and own a timer which controls when their block heaters are turned on, which saves money and fuel.

One innovative solution to combat the loss of energy by the cooling of engine oil has been developed by the engineers at Toyota. The new Toyota Prius actually pumps the hot engine oil into a thermos when the car is turned off. There it can be stored and remain warm for up to 3 days. When the car is switched on, the oil is then simply pumped back into the engine oil sump where it can then be used by the little four-stroke engine.

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Corky Bells Maximum Boost

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MSRP:

The base price is calculated using a 2011 Yamaha Phazer MTX

Flex Fuel Yamaha Phazer MSRP	
Base Price	$8,299
Power Commander	$350
Ignition Module	$300
Wideband Commander	$400
Catalytic Converter	$100
Labor	$250
Total	$9,699