THE UNIVERSITY OF BRITISH COLUMBIA

MECH 456

Biodiesel Engine Compatibility Study

Submitted to:
Dr. Steven Rogak

Submitted by:
Chris Glencross
David Lautner
Jeff Nelson

Submitted:
April 30, 2004

Executive Summary

The objectives of this project were to show the effects of varying U.B.C. biodiesel content in fuel on engine performance, to observe the performance of a specific low horsepower diesel engine such as the one used by U.B.C. plant operations and to gather data and observations to allow for improvements in the test apparatus.

In order to satisfy these objectives the project team procured an engine, a dynamometer, a testing facility, and funding required for purchasing additional equipment. Design work centered on an engine to dyno shaft adapter plate, an engine frame and a bell housing. Additionally, fuel system and data acquisition hardware was obtained.

Testing results showed a fundamental relationship between engine performance and biodiesel fuel blend. Typically, it was found that performance was reduced as the content of biodiesel increased in the fuel. However, the data did not conclusively show how specific changes in the fuel blend affected performance. However, it was important to note that none of the fuel blends caused a significant change in performance.

In light of the issues presented with the operation of the test apparatus several key recommendations are made. First, additional testing is necessary to better understand the variation in engine performance with biodiesel fuel blend. This should include extended testing periods aimed at understanding the long-term effects of biodiesel on engine life and component wear. Second, the test apparatus requires improvements to the exhaust system, shaft connection between engine and dynamometer and bell housing to both reduce vibrations and increase the safety for extended testing periods.

Table of Contents

Executive Summary i
List of Figures iv
List of Tables iv
1.0 Introduction 1
  1.1 Biodiesel 1
  1.2 Motivation for Engine Testing 2
  1.3 Test Objectives 3
  1.4 Expected Results 4
  1.5 Finance 5
2.0 Test Apparatus 7
  2.1 Engine 7
  2.2 Fuel System 9
  2.3 Dynamometer 9
  2.4 Data Acquisition 10
  2.5 Engine Frame 10
  2.6 Engine-to-Dyno Power Transfer 12
  2.7 Bell Housing 13
  2.8 Safety 14
3.0 Testing 16
  3.1 Test Procedure 16
  3.2 Data Processing 17
  3.3 Results 18
4.0 Discussion 24
  4.1 Test Apparatus Performance 24
  4.2 UBC Biodiesel Performance 26
  4.3 Sources of Error 27
5.0 Recommendations and Conclusions 30
  5.1 Test Apparatus 30
  5.2 Testing 30
  5.3 Biodiesel 31
Appendix A - Finances 33
Appendix B - Engine Specifications 34
Appendix C – UBC Biodiesel Analysis 36
Appendix D – Biodiesel Material Compatibility 37
Appendix E – Engine Stand Drawing 38
Appendix F – Adapter Plate Drawing 39

Appendix G – Bell Housing Drawing 40
Appendix H – Sample Calculations 41

List of Figures

Figure 1 - Production of Biodiesel - http://www.biodiesel.org/pdf_files/Production.PDF 1
Figure 2 - AMPEL High Head Lab.. 6
Figure 3 - Complete Test Assembly 7
Figure 4 – Kubota Super 05 V-Series Engine.. 8
Figure 5 - Fuel System... 9
Figure 6 – Superflow Control Bench and Dynamometer 10
Figure 7 – Engine Frame Mounted to Dynamometer Frame.. 11
Figure 8 – Dyno Spline (left) and Assembled Adapter Plate and Shaft (right) 12
Figure 9 - Bell Housing... 13
Figure 10 – Performance Curve Comparison Start of testing.. 18
Figure 11 - Performance Curve Comparison End of testing.. 19
Figure 12 – Diesel Performance Curve Comparison Figure 13 – B20 Performance Curve Comparison 20
Figure 14 – B40 Performance Curve Comparison Figure 15 – B60 Performance Curve Comparison 20
Figure 16 – B80 Performance Curve Comparison Figure 17- B100 Performance Curve Comparison 21
Figure 18 – Endurance Run Fuel and Torque Comparison 22

List of Tables

Table 1 – Fuel Consumption of the Various Blends.. 23
Table 2 – Power Output at 2700 RPM during Performance Test 1 27
Table 3 - Power Output at 2700 RPM during Performance Test 2... 27

1.0 Introduction

1.1 Biodiesel

Biodiesel is a non-petroleum based alternative fuel for compression ignition engines. Biodiesel is defined as a ethyl or methyl ester derived through a transesterification reaction, from animal fat, vegetable oil, or algae[1].

Transesterification is a catalyzed reaction that converts the raw material, such as vegetable oil, into usable biodiesel. The reaction occurs at low temperatures (approximately 150°F) and pressures (approximately 20 psi) and has a high recovery rate of about 98% so there is minimal waste. The glycerin that is produced as a by-product can then be used in other product such as soap. Figure 1 shows the production of biodiesel in block diagram form.

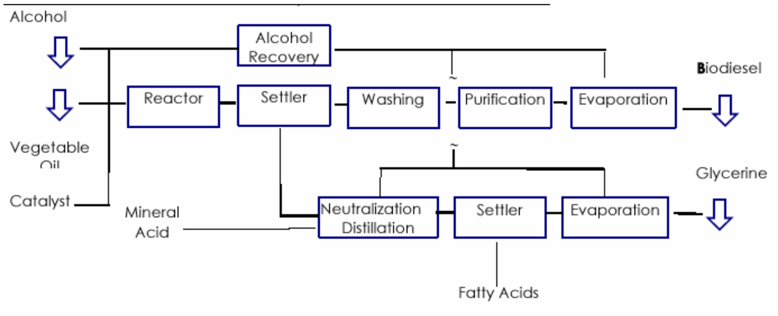


Figure 1 - Production of Biodiesel - http://www.biodiesel.org/pdf_files/Production.PDF

Biodiesel produced from the reaction is a non-aromatic compound that has a low sulfur content. Because of its' chemical composition, biodiesel has a much more pleasant smell then diesel. Other environmental advantages that biodiesel has over diesel is that biodiesel is considered non-toxic, biodegradable, and renewable. Biodiesel has a higher flash point which makes it easier to handle and store.

---

[1] Peterson C., Hammond B., Reece D., Thompson J., Beck S. Performance and Durability Testing of Diesel Engines Using Ethyl and Methyl Ester Fuels. National Biodiesel Board, Contract #52016-1, 1995.

Little or no modifications are needed to make a compression ignition engine (diesel engine) run on biodiesel. If an engine is run on biodiesel, a small change in performance can be expected. The energy content of biodiesel is approximately 10% less than that of regular diesel. This equates to a small decrease in performance. This decrease in performance is offset by a reduction in emissions produced. When biodiesel is used a reduction in Carbon Monoxide, particulate matter and hydrocarbons has been recorded, although it does show a slight increase in NOx emissions[2]. Biodiesel also has a higher lubricity than regular diesel. This increase in lubricity will increase engine life and lower maintenance costs.

Biodiesel is also very closely monitored by the government, especially in the United States. Commercial biodiesel is now considered an alternative fuel by the EPA and specifications have been developed by industry under ASTM D-6721 and ASTM PS 121[3]. Biodiesel also meets California Air Resources Board clean diesel standards and has been designated as an alternative fuel by the Department of Energy and the US Department of Transportation. Canada has also invested significant resources into biodiesel research. Within Ontario Biodiesel has a $0.143 / Liter tax break to offset the higher cost of production[4] and is currently being used by Saskatoon Transit Services and Toronto Hydro among others.

1.2 Motivation for Engine Testing

Over the past few years the Chemical Engineering department at UBC has been experimenting with the production of biodiesel using Food Services waste vegetable oil. To date the biodiesel has been produced in small batches and used in non-UBC equipment. As such, minimal feedback has been given to verify its' suitability for wide spread use in equipment at UBC. Shortly, a new biodiesel plant will be commissioned upping the production capacity to 500L per week. With this increased production a customer, namely Plant Operations, is needed. By performing engine testing it is hoped that the effects of switching to various blends of UBC

---

[2] A Comprehensive Analysis of Biodiesel Impact on Exhaust Emissions, EPA420-P02-001, 2002

[3] Tyson , Shaine K. Biodiesel Handling and Use Guidelines. National Renewable Energy Laboratory Report # NREL/TP-580-30004, 2001

[4] http://www.gov.on.ca/OMAFRA/english/policy/lifesciences/biodiesel.html
http://oee.nrcan.gc.ca/vehiclefuels/biodiesel/biodiesel_faq.cfm?PrintView=N&Text=N

produced biodiesel will be scientifically demonstrated to the parties involved in the Biodiesel Initiative.

1.3 Test Objectives

The purpose of defining test objectives was to ensure that the project goals met the requirements given to the project team by the various supervisory individuals and organizations. As such, the testing phase of the project had three key objectives. Namely, the test objectives were:

1. Indicate the performance of a low horsepower diesel engine, such as used by plant ops, using waste vegetable oil derived biodiesel produced at U.B.C.
2. Show the effects on engine performance of varying the biodiesel content in the fuel
3. Gather data and observations to allow for more refined methods and data collection in subsequent tests

The intent of the first objective was to allow the project team and interested parties to understand the effects of biodiesel on the performance of the engines. This is important in that it allows the stakeholders to make trade-offs between performance losses and gains attained by using biodiesel. Also, by measuring the performance of the diesel engine using biodiesel it was possible for the team to communicate with the U.B.C. Biodiesel Initiative Project members the performance of their biodiesel.

The second objective defined the scope and detail of the testing schedule. By requiring testing of various blends of biodiesel it would make it possible for the team to make estimates of the percent change of performance indicators. Another important feature of this method was the ability of the stakeholders to make more informed decisions on what type of blend to use in their vehicles by comparing an acceptable level of performance loss and a fuel blend that met those criteria.

The third objective was important for two reasons. It was present to ensure that while data was collected, sources of error in both the experimental apparatus and test procedure would be uncovered. This was accomplished by noting issues encountered throughout the testing phase.

In addition it would transfer the knowledge about the test apparatus to future groups so that the apparatus and testing methodology is improved.

1.4 Expected Results

Prior to testing the varying blends of fuel on the engine, a number of observations were anticipated. The reasoning for these observations came out of reading prior work in this area and noting the results of such reports and analyses. The anticipated trends formulated by the group are included for comparison so that results from this report may be evaluated against prior work. The trends that the group anticipated prior to testing may be broken down into three categories:

1. Performance variation of the engine (peak power and peak torque) based on fuel blend
2. Potential clogging and degradation of fuel system performance.

The most obvious anticipated trend was a reduction in peak power and torque by switching to biodiesel. The lower heating value of biodiesel is typically 10% lower than that of diesel and so it was expected to see a drop in performance of the engine. Also, the reduction in peak torque and power would be expected to drop somewhat linearly as the biodiesel content increases. The fundamental relationship concerned here is the combustion of fuel to generate energy. By switching to biodiesel the energy content per cycle is reduced. Since torque is related to the force generated by each expansion cycle of the engine it is expected that torque would be reduced. Similarly, the power generated by the engine is proportional to the torque of the engine at a given RPM thus a reduction in torque equates to a proportional reduction in power.

Given that testing will be conducted on a robust low horsepower engine, the group anticipated that the engine would perform satisfactorily regardless of the fuel blend. The effects of biodiesel on the life of injectors, fuel lines and fuel filters are highly dependent on the design of such components and vary engine to engine. However, the scope of testing did not include inspection of engine components due to resource constraints. Therefore, it was not possible to inspect the validity of any claims about component loss of function. The only method available for evaluation of component loss of function was through qualitative observations of changes in operating characteristics.

1.5 Finance

Engine testing can be a costly endeavor. This project required the acquisition of three main components: an engine, dynamometer, and testing space. The money allotted by the UBC Mechanical Engineering department for a project course of this nature would not suffice and outside support was needed. A breakdown of the project's financial spending can be found in Appendix.

The engine is an expensive piece of equipment that would be required to complete the testing. To acquire an engine, Kubota was approached because they supply UBC plant operations with equipment and the expense would have been prohibitive to the project. Kubota Canada was willing to donate an engine because they have an interest in both biodiesel and supporting Canadian universities.

To test the engine a dynamometer is required. A Superflow SF-901 dynamometer was provided by the UBC Mechanical Engineering Department. Custom fabrication was still required to enable the engine to mount to the dynamometer. The pieces needed were designed by the project team and fabrication was outsourced. The Alma Matter Society (AMS) donated $2000 towards the project through the Innovative Projects Fund (IPF) to help pay for these modifications.

With the dynamometer and the engine in order, a suitable place for testing needed to be found. Very specific requirements were needed for the testing area. It had to be a secure, ventilated building with access to a pressurized waterline and a drain. All these requirements were met and provided by the AMPEL High Head Lab at UBC (Figure 2).

Figure 2 - AMPEL High Head Lab

2.0 Test Apparatus

The test apparatus shown in Figure 3 consist of several main components: engine, fuel system, dynamometer, data acquisition system, engine frame, engine to dynamometer drive shaft, and bell housing. The following sections describe the individual components of the test apparatus.

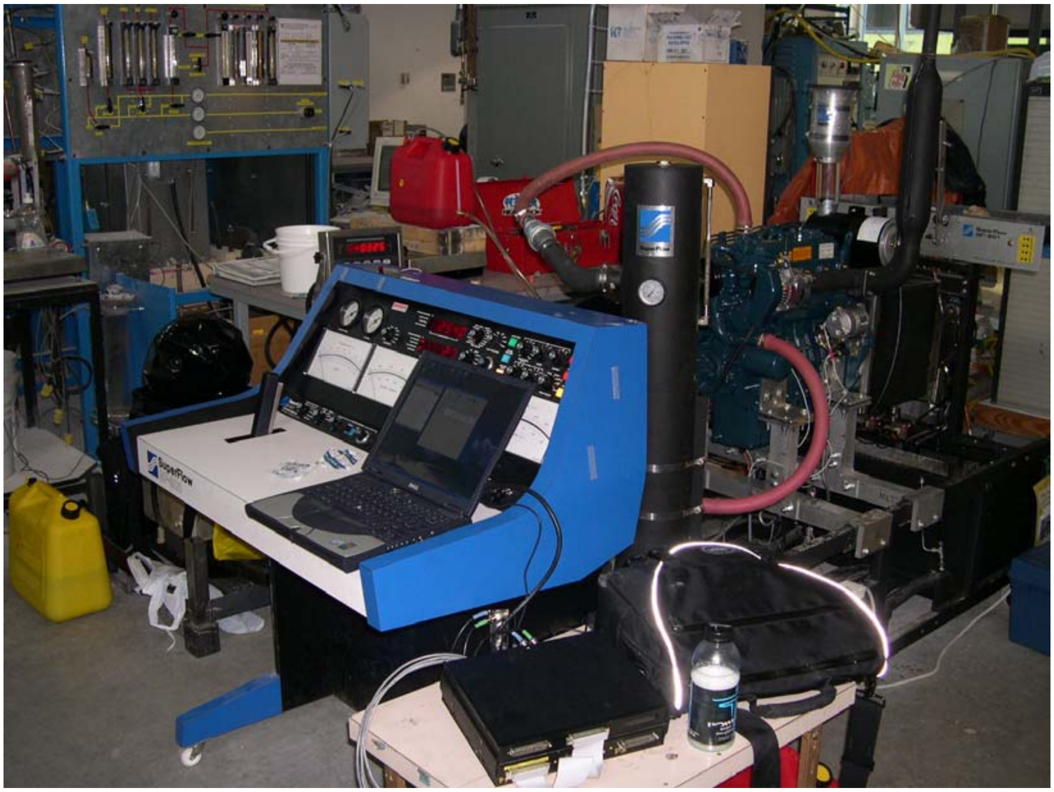


Figure 3 - Complete Test Assembly

2.1 Engine

The engine selected for testing was a Kubota V1305-E 1.3L, four cylinder, liquid cooled, indirect injection diesel. The engine is rated to produce 30 hp at 2700 rpm. A goal of the Biodiesel Initiative at UBC is to have Plant Operations consume the biodiesel produced, therefore it was deemed important to pick an engine that they used. Given UBC Plant Operations uses a number of these engines in their Kubota F3060 lawn tractors, it was felt this would be a good candidate for testing UBC produced biodiesel.

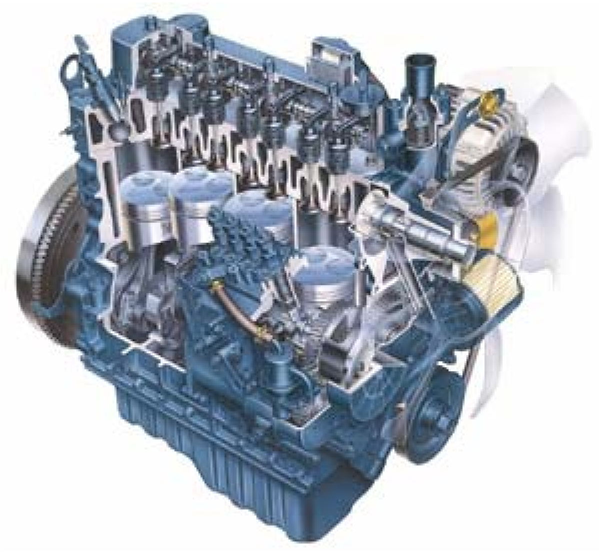


Figure 4 – Kubota Super 05 V-Series Engine

A new, stripped down V1305-E, as shown above, was sent from Kubota Canada to perform testing. To this engine an air filter, muffler, and fuel filter were added. All of these parts were standard Kubota parts for the V1305 engine. The only modifications made to the engine were the removal of the cooling fan and the change of all rubber fuel lines to polyethylene lines.

For a complete listing of the manufacturer engine specifications please refer to Appendix B.

2.2 Fuel System

Fuel consumption is important for these tests to enable a proper monitoring and performance evaluation of the engine. To measure fuel consumption the pail and scale method was used. This method has proven more accurate than flow meters for low flow rates and accounts for the amount of fuel returned to the tank from the injectors. The scale used in this case was an IQ Plus 355 series digital scale. A BNC plug was attached to the voltage outlet of the scale so that the Data Acquisition system (DAQ) could monitor the weight of the fuel at the same time as it recorded the torque and RPM.

The fuel system hoses were also changed to polyethylene because biodiesel has shown to be incompatible with some rubber used in fuel systems[5]. Polyethylene hoses were run from our fuel tank (pail), a modified nine liter jerry can, to our engine (see Figure 5).

Figure 5 - Fuel System

2.3 Dynamometer

The dynamometer used for testing is a Superflow SF-901 water brake style dynamometer with a classic control bench (see Figure 6). Outputs currently available from the dynamometer are RPM, torque, and airflow. The dynamometer has the ability to output fuel flow and various temperatures and pressures, however for the scope of our testing only RPM, torque and airflow will be taken from the dynamometer. The dynamometer is rated for up to 1500 hp and as such

---

[5] Tyson , Shaine K. Biodiesel Handling and Use Guidelines. National Renewable Energy Laboratory Report # NREL/TP-580-30004, 2001

has more than enough capacity to handle the 30 hp Kubota engine. A representative from Superflow was contacted regarding the suitability of the SF-901 for this application and the only concern made was low RPM loading of the engine may be difficult.

Figure 6 – Superflow Control Bench and Dynamometer

2.4 Data Acquisition

Continuous monitoring of the engine performance was wanted for the tests. The dynamometer had previously been modified with BNC plugs to measure the raw torque and RPM as a voltage. The scale had a sensor voltage outlet with a BNC plug as well. An IOtech DAQBOOK 120 was used with DAQView and a DBK18 four channel filter card to measure the voltages. Performance parameters recorded were RPM, raw torque and fuel weight. This allowed the calculation of power and fuel consumption throughout the test.

2.5 Engine Frame

The primary role of the engine frame was to support the vertical load of the engine and bell housing. Additionally, the engine frame was designed to reduce vibration transfer from the engine to the dynamometer frame and to carry torque loads generated by the engine should a failure occur in the bell housing. Refer to Appendix E for a drawing of the engine frame assembly (two identical assemblies are used to support the engine). Fabrication and material cost were also important factors in determining the final design.

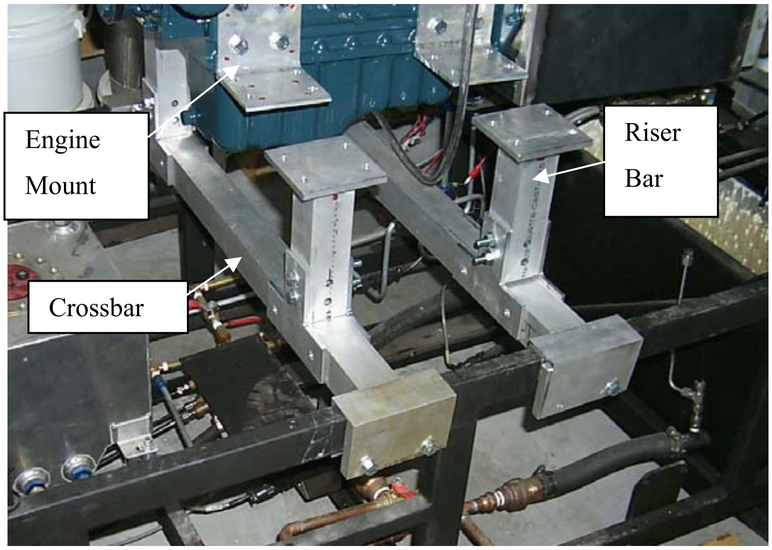


Figure 7 – Engine Frame Mounted to Dynamometer Frame

The layout of the engine frame was a simple four post arrangement that bolted directly to four engine mounts. The x and y position (in the plane of the floor) of the four posts was made adjustable by using bolts and drilling holes in the crossbars after the engine was attached to the dynamometer. The vertical position of engine mounts was determined by using drawings of the engine and dyno frame and allowing a ¼ inch tolerance that would be made up to suit by shimming. This method proved advantageous as the exact position of the engine was not precisely known due to alignment with the dynamometer spline shaft. The sizing of the members was chosen to fit the dimensions of the dynamometer frame and to provide a design factor large enough to withstand the potential moments generated by the engine torque.

To reduce the cost of the engine frame the fabricator was advised that the material specifications and tube wall thickness could be altered to accommodate stock parts available at their shop. This resulted in vertical riser bars that were 2.5 inches square with 1/4” wall thickness. The horizontal crossbars were also 2.5 inches square with ¼" wall thickness. The manufacturing drawing called for using mild steel but the fabricator used aluminum stock for the same price.

To limit vibration transfer from the engine to the engine frame and the rest of the apparatus rubber grommets were installed between the engine mounts and riser bar end plates. As a further measure to reduce vibration and increase friction between the crossbars and dynamometer frame 1/8" thick EPDM rubber sheets were cut and placed overtop of the dyno frame where the crossbars rested on the frame. This was beneficial in that it created a tighter fit between the two tubes.

2.6 Engine-to-Dyno Power Transfer

The Superflow dynamometer is setup for a direct bolt-on of a small block Chevrolet engine. As such, to enable the hook up of the Kubota engine some adaptation was required. A connection needed to be made between the splined input shaft of the dynamometer and the flywheel of the engine. From a previous dynamometer adaptation, the Formula UBC team had built a female splined shaft with a four bolt flange on the opposite end. This shaft both simplified the design and cost of mating the engine and dynamometer. Essentially all that was needed to drive the dynamometer was an adapter plate between the flywheel of the engine and the four bolt flange of the Formula UBC shaft. The assembled adapter plate and shaft and dynamometer spline can be seen below. For a complete drawing of the adapter plate please refer to Appendix F.

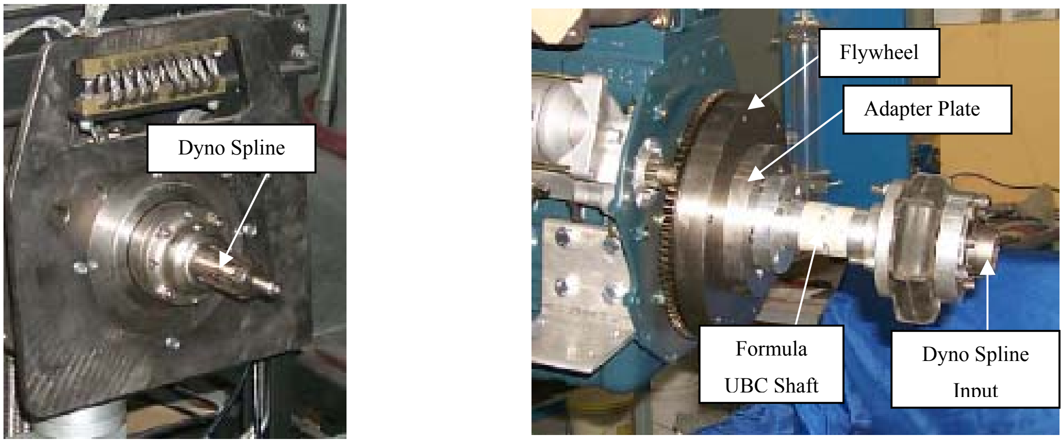


Figure 8 – Dyno Spline (left) and Assembled Adapter Plate and Shaft (right)

Given that this setup does not involve a clutch, a method of disconnecting power transfer in the event of a system jam had to be in place. This had been addressed previously by the Formula UBC team and in designing the shaft a shear pin setup was used.

2.7 Bell Housing

A means of rigidly joining the engine to the dynamometer was needed, much like an automotive bell housing, to join an engine to a transmission. The reason for doing this is two-fold. Firstly, the fabricated bell housing removes the moment from the dynamometer. This allows the dynamometer to be able to just measure the torque produced and not "take" any torque, which the dynamometer was never designed to do. Secondly, reason for the bell housing was safety shield. The engine turns a shaft that is rigidly connected to the dynamometer. If the shaft broke the shrapnel could be very dangerous. The bell housing will contain the shrapnel.

The bell housing was fabricated out of $^1/_8$" mild steel plate and formed into an open ended box as seen in Figure 9 and an isometric drawing can be found in Appendix .

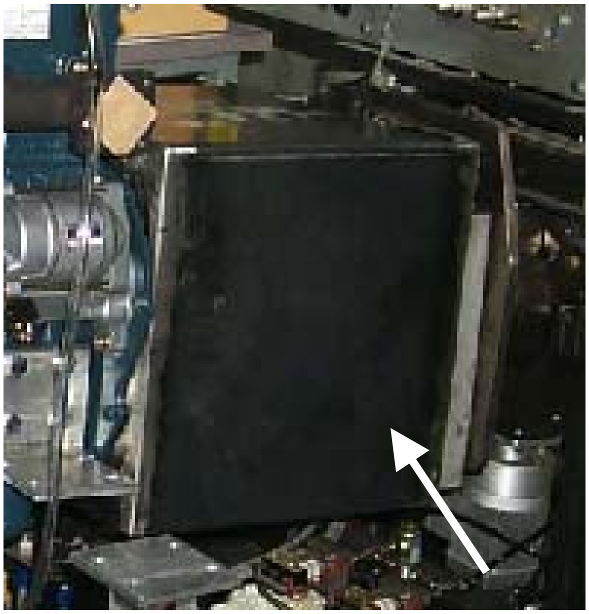


Figure 9 - Bell Housing

2.8 Safety

Safety was an important aspect of testing. The design of the apparatus included consideration of sources of energy and ways to ensure that people near the vicinity of the apparatus were safe. The sources of energy that present safety concerns include:

1. Engine drive shaft and attached components

   The drive shaft was encased in the bell housing designed for this apparatus so that in the event of disengagement of any parts or release of bolts, nuts, etc. the bell housing would contain these parts and they would drop out to the floor.

2. Dynamometer shaft

   The dyno shaft was secured via the engine bell housing and dyno frame.

3. Pressurized water intake line

   The water intake line at only operated at 6-8 psi so there was no specific protection required against this item.

4. Cooling tower

   The cooling tower contained cooling water for the engine and operated at roughly 76 degrees Celsius. To protect against a release of high temperature water the tower contained a pressure release valve to maintain set system pressure and a regulator was attached to maintain correct water temperature.

5. 12 volt battery and connected electrical wiring

   The system was protected against short circuits by the addition of fuses coming from the positive terminal of the battery to the engine starter and ignition. The Instrumentation equipment was protected by using power from the building electrical outlets. The electrical panel contained 30A grounded 120V AC outlets and the equipment was connected to the panel through a surge protection bar. The surge protector and cord plugs were raised off the ground to prevent against water contact.

6. Engine exhaust

   The engine exhaust gases were routed to a scrubbed ventilation duct via a high-temperature flexible duct.

Additionally, personal protective equipment was used by the group during testing. Ear protection was worn to reduce the noise level to acceptable levels and eye protection was worn. The team walked through the building to familiarize themselves with the location of the nearest fire extinguishers, eye wash stations and emergency showers. Also, emergency contact information was written down near the controls. Finally, an engine kill switch was wired up to the engine ignition and the use of a manual fuel shut-off lever was confirmed.

3.0 Testing

Following assembly of the test apparatus, a limited amount of time was left for testing. As such, a very basic test matrix was followed. The fuels selected for testing were No. 2 Diesel, for a baseline, B20 (20% biodiesel by volume), B40, B60, B80, and B100. All biodiesel used in the tests came from UBC Biodiesel produced on March 23, 2004 and was splash blended with No. 2 Diesel. Each fuel was then engine tested, first with an approximately 15 minute performance test followed by a one hour steady operation test and a subsequent 15 minute performance test. By comparing the performance test at the start of testing and the performance test following the one hour steady operation test, if performance degradation occurred it would be apparent. For an analysis completed on the UBC Biodiesel please refer to Appendix.

3.1 Test Procedure

At the start of all test days, a DAQ system calibration was conducted. First the appropriate range for the torque, RPM, and fuel weight were set in the DAQ. Each input was then zeroed and a range of torques, speeds, and weights were applied to the respective sensors. From this, a linear relationship between actual input and voltage output could be attained. While this calibration should not change from day to day, in this situation, the DAQ system was being shared by a number of groups and the potential for changes being made existed.

Following calibration, testing commenced. For each fuel, a four step test procedure was followed. Initially the engine was started and ran for approximately 10 minutes at 2700 RPM under load. This ensured the engine was up to operating temperature and that any residual fuel from previous testing was removed from the system.

The first performance test was then obtained. This was done using a steady state test method. The engine was set to wide open throttle (WOT) and the dynamometers load control was set to servo. With the dynamometer in servo mode, the maximum load the engine can handle at a given RPM is applied. The operator then dials in the desired RPM with the control on the dynamometer bench. A minimum of six RPM steps were made between 1600 and 2800 RPM. At each step the RPM was held constant for at least 5 seconds. To perform the SAE Correction factor calculation, temperature, barometric pressure, and relative humidity were collected during the test. During performance testing the DAQ was set at a sampling rate of 10 Hz.

Following the first performance test, a 1 hour steady operation test was conducted. The dynamometer was left in servo mode and the engine speed was set to 2700 RPM. To perform the SAE Correction factor calculation, temperature, barometric pressure, and relative humidity were collected at the beginning and end of the test and an average was taken. During the 1 hour test, the DAQ was set at a sampling rate of 2 Hz for 7800 points to limit the file size.

Finally, the end of testing performance curve was obtained. The same procedure was used here as was used for the first performance curve.

3.2 Data Processing

Voltage recorded during testing were imported into a excel file. Once in the excel format the data could then be processed. To convert the voltage into values a full calibration of torque, RPM and weight was done daily. The calibration procedure included zeroing the DAQ and then using known quantities to "load" the system. The voltage was then recorded with the corresponding load. A linear best fit line was then drawn through the data (usually with an $R^2 = 0.999$) to establish the gain and offset of the instruments. The DAQ was then considered ready for testing.

The equation for the linear line was used to convert between voltage and the actual values. The SAE correction factor was then applied to the calculated torque value to account for daily fluctuations. Power was then calculated from the corrected torque values (see Appendix for sample calculations).

Data scatter during the performance runs was an issue during the data processing. The dynamometer normally takes a three second running average of the values to smooth the data. This acts as a digital filter but causes an inaccuracy in the dynamometer reading. To correct for this inaccuracy, the transient points between the steady state steps were removed from the data set. The RPM and the corrected torque were then averaged for each steady-state RPM to make the plots. The power was then calculated using the RPM and the corrected torque.

3.3 Results

From the three different tests (Performance 1, Endurance, and Performance 2) and the six different blends of fuel, a number of comparisons could be made. The following plot compares the different blends' performance curves during performance test 1.

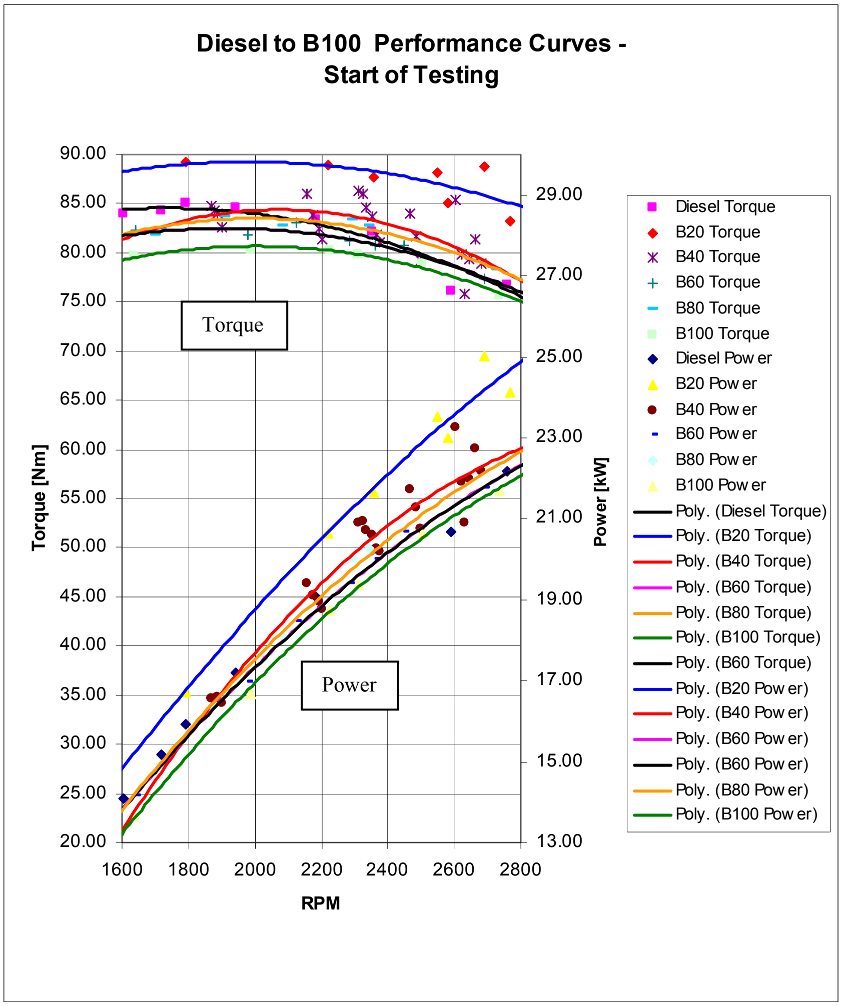


Figure 10 – Performance Curve Comparison Start of testing

From the above plot a few things should be noted, B20 results appear to be shifted significantly higher than the other fuels tested and the expected trend of decreasing power with increasing biodiesel content was not consistently observed. Both these issues require further investigation. A comparison of the performance curves obtained at the end of testing yield similar results to the first curves. A plot comparing the second performance curves from the various fuel blends can be seen below.

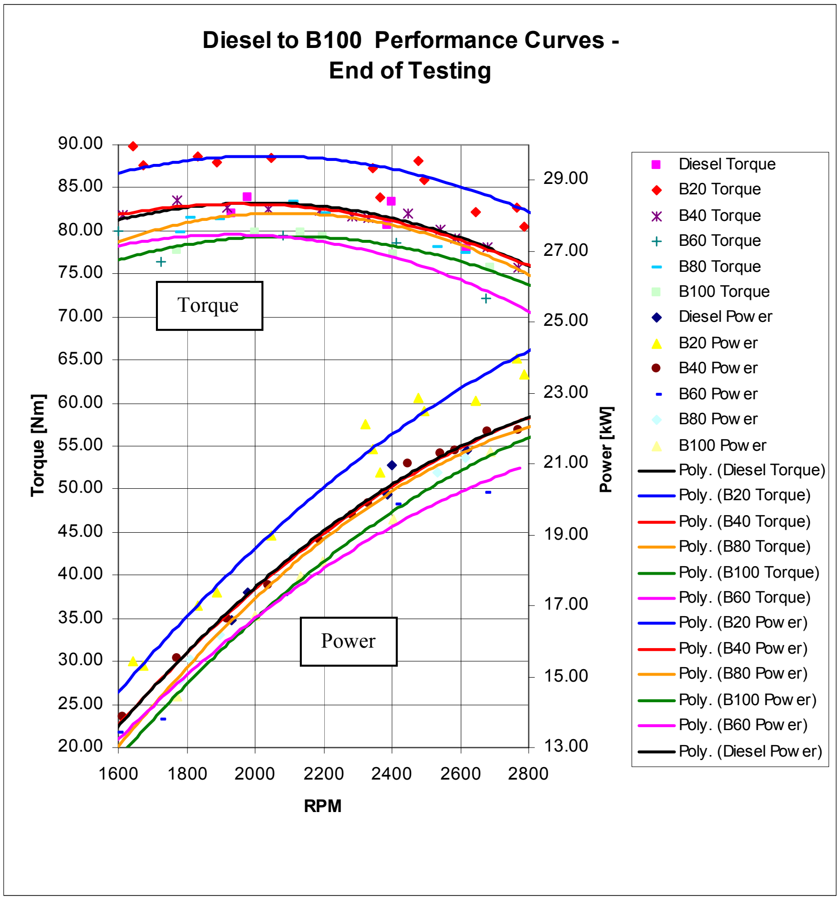


Figure 11 - Performance Curve Comparison End of testing

Again B20 was shifted significantly higher than the rest of the blends and the trend of decreasing power with increasing biodiesel content was not consistently observed.

Another comparison of interest is the start of testing (P1) and end of testing performance curves (P2) of the individual fuel blends. From this comparison degradation of engine performance, if present, may be shown. The before and after comparisons of Diesel, B20, B40, B60, B80 and B100 follow.

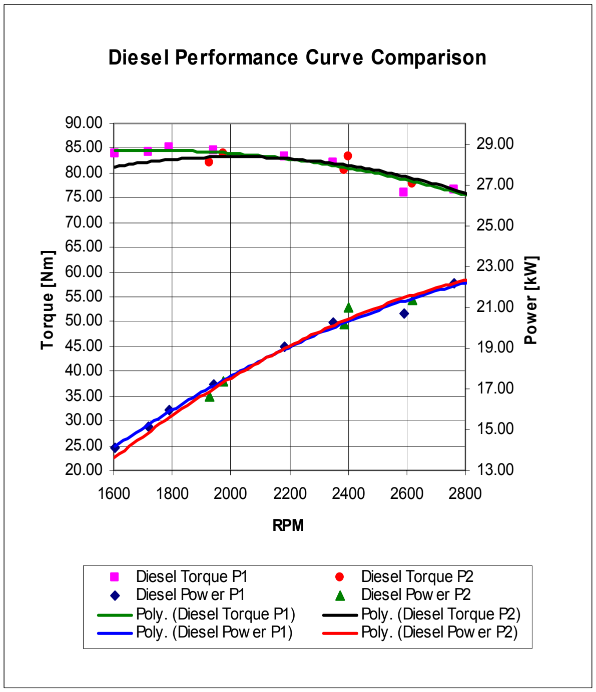


Figure 12 – Diesel Performance Curve Comparison

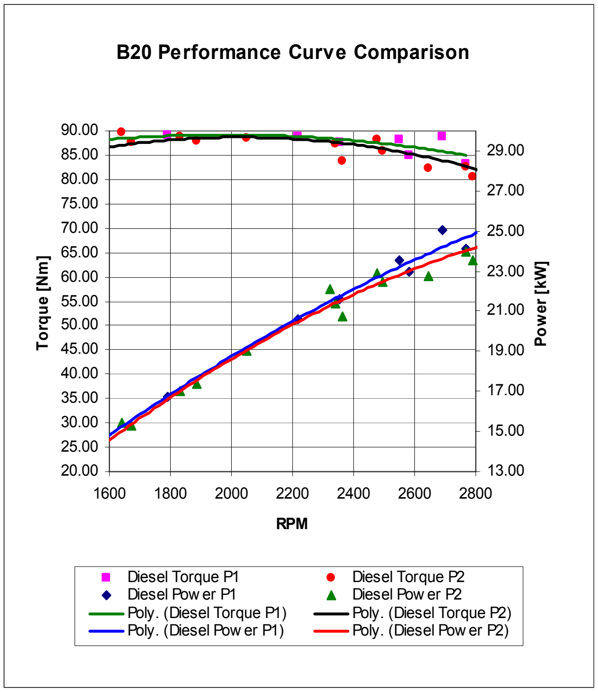


Figure 13 – B20 Performance Curve Comparison

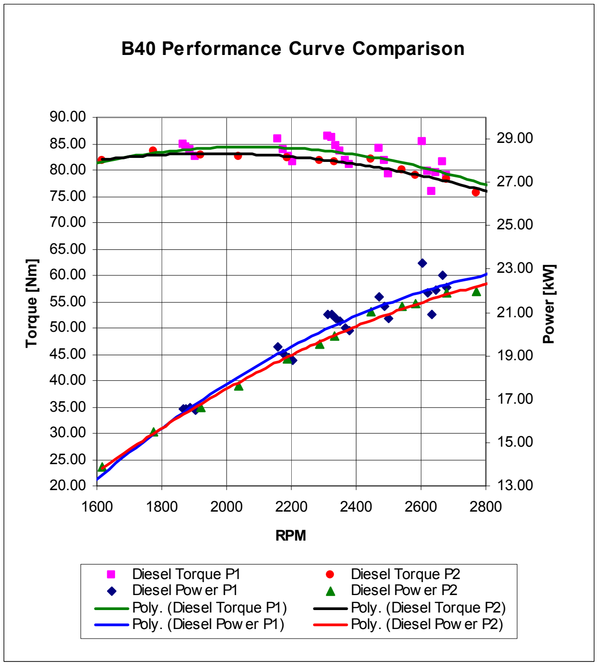


Figure 14 – B40 Performance Curve Comparison

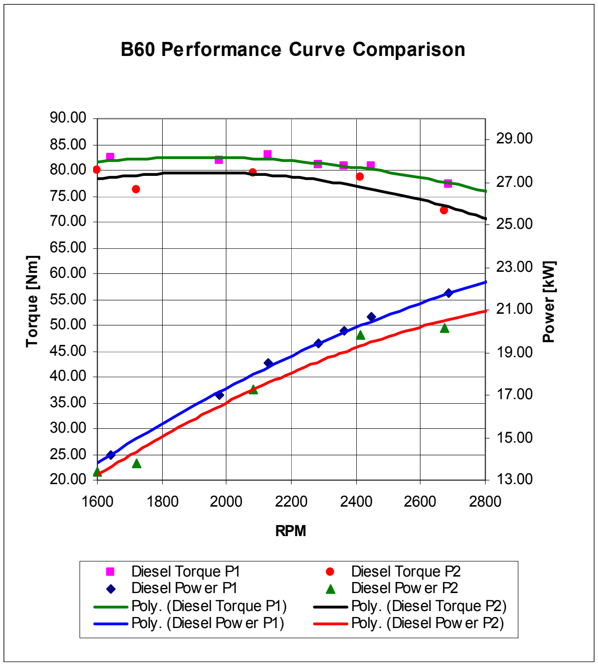


Figure 15 – B60 Performance Curve Comparison

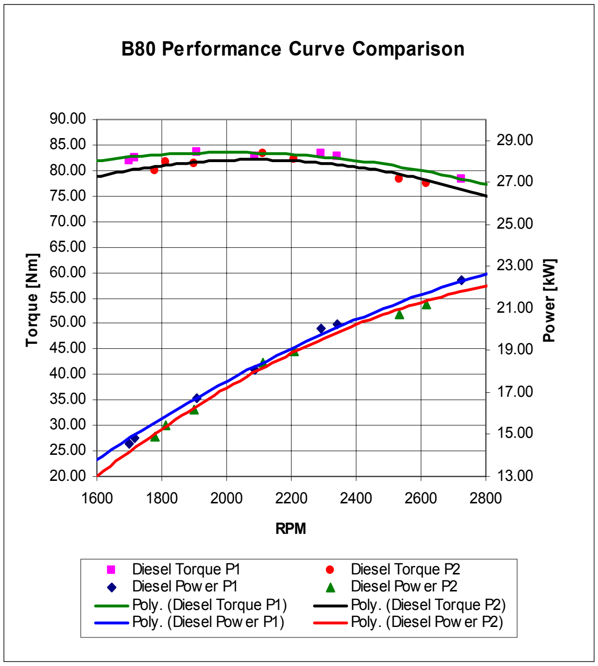


Figure 16 – B80 Performance Curve Comparison

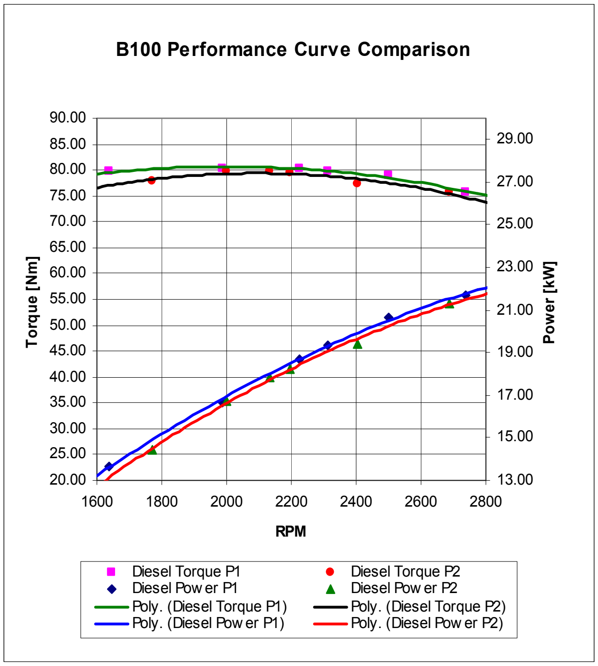


Figure 17- B100 Performance Curve Comparison

Of the above plots, the only blend that showed a significant amount of change from start to finish was B60. Even with this case the difference between start and finish was less than 2 kW change in power output. However, this does not follow the trend of minimal change (less than 1 kW) in performance of the rest of the fuel blends, most importantly the higher blends B80 and B100.

The next comparison pertains to the data collected during the endurance. Both fuel weight and torque were analyzed with respect to time over the one hour run. The following plot shows this data.

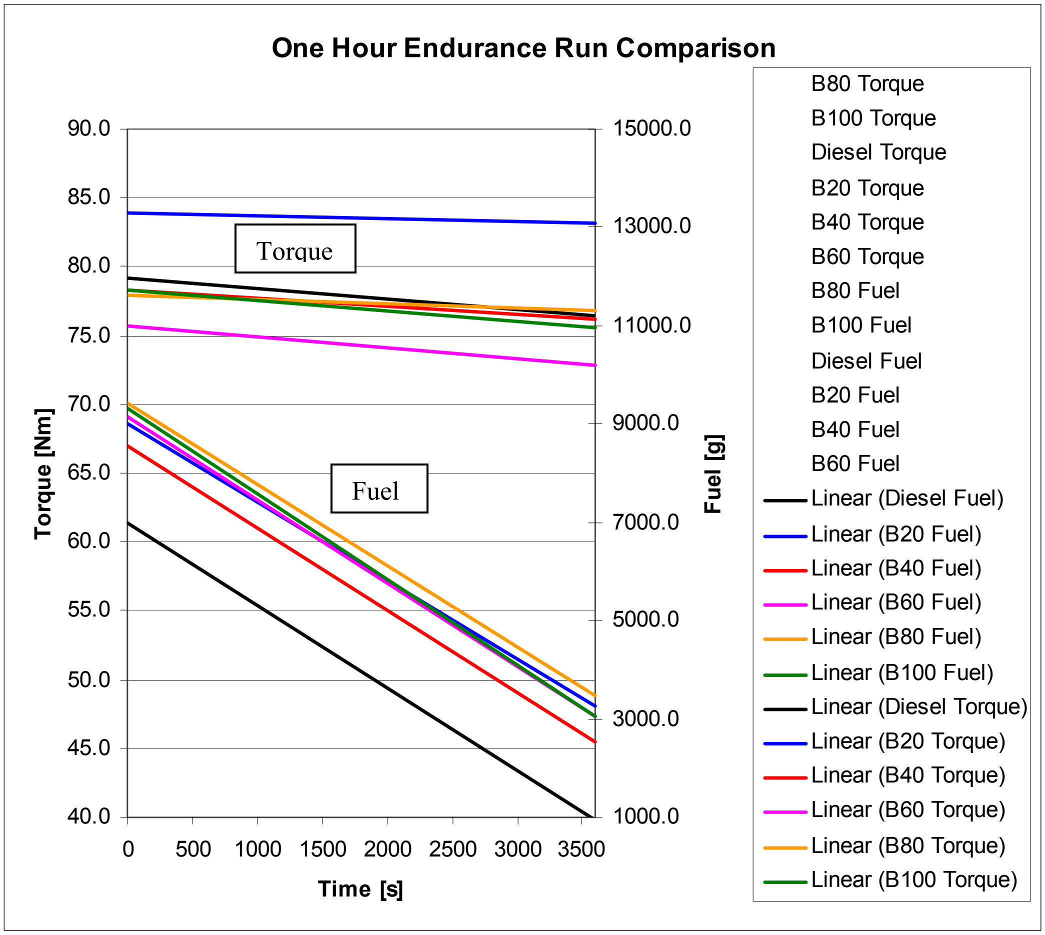


Figure 18 – Endurance Run Fuel and Torque Comparison

Both during the test run and during analysis it was noted that the Torque tended to drift approximately 2 Nm lower than the original value over the one hour test. This was consistent with each fuel and there for can not be seen as engine degradation due to fuel. For all blends of fuel, the fuel consumption was constant over the run and hence a linear trend was developed over time. The following table summarizes the fuel consumptions of all the blends.

Diesel	**Fuel Consumption**		**Average Power**	
y = -1.6765x + 6976	1.68	g/s	21.88	kW
R2 = 0.9997	6035.40	g/h		
	275.78	**g/kWh**		
B20	**Fuel Consumption**		**Average Power**	
y = -1.5904x + 8993	1.59	g/s	23.42	kW
R2 = 0.9987	5725.44	g/h		
specific	**244.45**	**g/kWh**		
B40	**Fuel Consumption**		**Average Power**	
y = -1.6814x + 8574	1.68	g/s	21.63	kW
R2 = 0.9998	6053.04	g/h		
specific	**279.90**	**g/kWh**		
B60	**Fuel Consumption**		**Average Power**	
y = -1.6951x + 9164	1.70	g/s	20.77	kW
R2 = 0.9999	6102.36	g/h		
specific	**293.75**	**g/kWh**		
B80	**Fuel Consumption**		**Average Power**	
y = -1.6548x + 9422	1.65	g/s	21.47	kW
R2 = 0.9969	5957.28	g/h		
specific	**277.44**	**g/kWh**		
B100	**Fuel Consumption**		**Average Power**	
y = -1.7487x + 9340	1.75	g/s	21.74	kW
R2 = 0.999	6295.32	g/h		
specific	**289.55**	**g/kWh**		

Table 1 – Fuel Consumption of the Various Blends

The fuel consumption in grams per second was determined from the slope of the fuel line and the power was averaged over the entire run. From these values, the specific fuel consumption of the various blends was determined. As with the inconsistent trends of the performance curves of the engine, the fuel consumption followed a similar pattern.

4.0 Discussion

4.1 Test Apparatus Performance

The test apparatus had a significant impact on the testing procedure and hence the test results. This section intends to describe the apparatus in terms of its components and the challenges faced with these components. Based on observations presented here, some suggestions for a future test apparatus are made in the recommendations section. The components discussed here include the engine, dynamometer, data acquisition equipment, engine frame, power transfer components, fuel tank, bell housing, and exhaust.

The engine appeared to perform well from the limited time that it was tested (approximately 10 hours). The Kubota V1305E came new from the factory and so there were not many issues present when switching it from diesel to biodiesel. The engine displayed high vibration in its low range (i.e. below 1500 rpm) typical of diesel engines but became very smooth above that. It is noteworthy that the ambient temperature never reached below 15 degrees Celsius in the testing area and so cold weather performance was not evaluated. Overall, this was an excellent engine and proved to be suitable for use with biodiesel.

The Superflow SF-901 dynamometer was well-designed and made setup easy. Calibration of the torque signal from the dyno was equally simple. Since this equipment was designed to handle upwards of 1500 hp the torque and power produced by the test engine was easily accommodated. One component that did not perform ideally was the water holding tank. Under moderate vibration the water surface created bouncing droplets that would escape the holding tank. A better design would have included dampers between the tank and the dyno frame. Finally, the data signals from the dyno to the data acquisition system had a high data scatter which resulted in measured voltages being variable by as much as 25% of the average. For this reason the data collected had to be averaged over longer periods of time to obtain reasonable estimates and trends.

The data acquisition equipment presented several issues. Calibration of the data card was difficult due to variation in the readout. Also, in several instances it was not possible to set the zero signal to 0 V and so values of 0.1 V were used. Another issue was the lack of data signals accommodated by the card. The card used accepted up to 4 signals whereas it would have been beneficial to collect many more inputs. Examples of such inputs include ambient temperature, barometric pressure, exhaust temperature and engine oil pressure.

The engine frame performed as intended and did not show any signs of fatigue or wear. There were, however, two areas that would likely have been improved for the future. The first would be the connection between the engine mounts and the riser bars. It was slightly challenging to get all four riser bars to line up correctly to enable inserting the fasteners. Also, the grommets used were not ideal and a design that incorporated a single larger grommet at each post would have been preferred. Finally, the connections between the crossbars and the dyno frame were not ideal because the fabricator used a channel size larger than was specified. This meant that plates had to be added between the channels to make them fit snug against the dyno frame.

The power transfer components made use of a shaft designed by Formula UBC. This shaft incorporated an unbalanced rubber disc that had no dampening properties and created vibrations in the shaft because of the unbalanced mass. This same shaft had a torque overload protection device in the form of a shear pin between two connected discs. In terms of the adapter plate designed for this project, it mated properly to both the engine flywheel and Formula UBC's shaft and did not create any problems.

The fuel tank and mass balance worked reasonably well given the test requirements. The concerns that arose during testing included temperature variations of the fuel, mixing of fuel blends, sizing of the tank and loss of fuel through evaporation. It was noticed during testing that at the beginning of a test the fuel temperature was at ambient. However, as the fuel moved through the engine its temperature rose noticeably and over the period of an endurance test the tank fuel became warm. The reason for the concern is that the fuel density changes with temperature and so the volumetric density would decrease from start to finish. Another issue was the mixing of fuel blends. This issue came up because fuel remaining in fuel lines would return into a fuel tank containing a different blend of diesel and biodiesel. Since the change in blend ratio would be minimal it was decided that running for ten minutes prior to collecting data would remove the old fuel from the lines and test results would reflect the correct mix. Another issue was the size of the tank. The fuel consumption rate was higher than expected and the position of fuel tank outlet was placed too high making it necessary to top-up the tank between performance runs (for a given blend). Finally, the fuel tank was open to atmosphere to prevent vacuum pressure inside the fuel tank. This meant that some of the fuel would escape the tank during testing resulting in a slightly higher fuel consumption rate than should have occurred. Again, since the loss in fuel due to vaporization was minimal this concern did not become a problem.

The bell housing design was acceptable but problems arose due to excessive vibration and poor fabrication. During the second half of testing it was noticed that cracks were forming along the bell housing weldments. This presented a significant problem in that the safety benefit of the bell housing was compromised and resonant frequencies set in causing significant noise in the building. The problem was addressed by stopping testing and removing the bell housing from the engine and dyno. The bell housing was then reinforced in the corners with ¼" angle iron. When the dyno and engine were reattached and testing resumed the noise issue was resolved and vibration in the bell housing was reduced significantly.

Finally, the exhaust ducting used was found to be undersized and therefore was not drawing 100% of the exhaust fumes. Another problem with the exhaust used was the vibration of the exhaust duct nearest the tail pipe. The combination of high temperatures and vibration allowed cracks to form in the duct material. The solution used was to remove the damaged sections of ducting between testing.

4.2 UBC Biodiesel Performance

The results from the biodiesel engine testing present inconclusive evidence to enable the selection of an optimum biodiesel blend. It is clear more testing needs to be conducted as a number of the tests, most notably B20, do not agree with the expected results. While these results may have some validity, without repeated runs to compare against, conclusions cannot be drawn. For performance test one the following table shows the fuels in increasing measured power output at 2700 RPM.

Fuel	Power [kW]
B20	24.25
B40	22.35
B80	22.2
Diesel	21.8
B60	21.8
B100	21.6

Table 2 – Power Output at 2700 RPM during Performance Test 1

In comparison, performance test two yielded the following measured power outputs at 2700 RPM.

Fuel	Power [kW]
B20	24.25
Diesel	22.25
B40	22.25
B80	22.1
B100	21.75
B60	21.0

Table 3 - Power Output at 2700 RPM during Performance Test 2

Again the consistency of this data is lacking and methods will have to be addressed as to how to correct it (See Recommendations Section).

These preliminary results do point towards there being minimal effect to switching to the varying biodiesel blends. While changes between the blends may be hard to discern the results do show that minimal performance was lost even switching to 100% Biodiesel. With all the blends of fuel tested, the engine started with ease and exhibited no signs of trouble moving throughout its' RPM range.

4.3 Sources of Error

There were a number of sources of error noticed during the test. These errors stemmed from both the testing apparatus and human errors.

Data scatter during a single test run remains one of the most significant factors affecting the data. More scatter occurred than was expected and it also increased with an increase in RPM. This could have stemmed from many different reasons including vibration, electrical interference, and data acquisition.

During the B40 testing the bell housing began to crack along the weld because of the vibrations of the engine. This caused a loss of rigidity in the system. The loss of rigidity may have increased the affected results and increased the data scatter. To quickly fix the bell housing during testing, angle iron was bolted into all of the corners. The loss of rigidity can easily be completely solved by re-welding the bell housing with a stronger weld before further testing is completed.

Increased scatter with increased RPM could also be a function of electrical interference. Due to the way the engine was configured a choice was made to leave the alternator intact. This not only created an unwanted load on the engine, it also created an electrical field. Because our DAQ system relies on relatively small voltage changes the electrical field could have affected the readings. Although it is unlikely that this is a major source of the scatter, any possibility of this error could be eliminated by removing the alternator. This would also remove the load on the engine and increase accuracy further.

The DAQ system does have error within it. The DBK18 card is accurate to within 0.2%. The card tuned to reach about 4.75 V on full load of 90 Nm. This implies that the voltage measured could be 4.74V or 89.8 Nm. The DaqBook 120 is accurate within 0.1%. This is then added to the DBK18 card's error to give an outside reading of 4.73% which is approximately 89.7 Nm. The error then is increased once more by the dynamometer load sensor. The load sensor is within 0.05%[6]. This translates to a maximum error of 0.3 Nm from the DAQ system.

The testing procedure was also a source of error in our experiments. The endurance runs were standardized as the DAQ did the run timings and the engine was dialed to a specific RPM and left. The performance curves were somewhat more difficult and prone to error. Using the load servo to raise the RPM, a steady state was achieved. Data points were then recorded though out.

---

[6] http://www.superflow.com/support/support-engdyno-how-is-torque-meas.htm

The time at steady state and the number of data points taken at a given RPM were somewhat randomized. This could have lead to inconsistency in engine performance. The randomization of RPM testing order would be considered a good practice but certain other guidelines should be imposed. These guidelines include minimum time spent at a steady state and specific engine speeds that must be tested (regardless of order).

5.0 Recommendations and Conclusions

5.1 Test Apparatus

The overall performance of the test apparatus was satisfactory. Two exceptions are the cracks that formed in the bell housing due to vibration and the under sizing of the exhaust ducting. That being said, the apparatus did function sufficiently to enable the group to collect engine performance data. Having limited financial resources and a short working schedule meant that not every aspect of the design was perfected. Therefore, trade-offs were made to maximize the likelihood of accomplishing the project objectives. It is expected that subsequent testing would be more rigorous and funding would be available for improving the test apparatus. With this in mind several general recommendations are made in order of decreasing importance.

1. Obtain a data acquisition that has at least eight input channels to enable monitoring of more performance variables.
2. Install exhaust emissions monitoring equipment and incorporate results into the performance of the various blends
3. Design and fabricate a more rigid bell housing that would have reduced vibration excitation problems.
4. Install larger diameter exhaust ducting to allow sufficient evacuation of exhaust fumes.
5. Improve the fuel tank system by using larger capacity tanks to accommodate longer test periods and use a second tank to recover fuel from fuel lines. The benefit of a second tank is to prevent mixing of different fuel blends when switching over.
6. Replace the solid drive shaft with a clutched assembly to increase the safety of the apparatus.

5.2 Testing

Continued testing is required for more accurate conclusions to be drawn. More accurate testing procedures must be developed and adhered to. Repeated tests (minimum three repeated tests per point) would also be advisable to help show repeatability and take into account conditions on different days. Endurance testing on an engine in plant operations would also be advisable so that long term affects could be more closely monitored.

5.3 Biodiesel

The biodiesel has shown no indication of problems throughout the testing, although these tests are not conclusive for an unmodified V1305 diesel engine. Research has shown that at lower blends there will be little or no adverse affects on the engine over a longer run. At higher blends there may be a slight clogging of fuel filters for the first five or six tanks of fuel if the engine has run on diesel for any significant amount of time. The reason for this potential clogging is biodiesel acts as a solvent and any residual diesel build up in the fuel components will be flushed through the system when biodiesel is added. By the end of the five or six tanks the fuel system should be clean and no further clogging problems should arise. During this time the fuel filter should be changed regularly.

Some decrease in overall performance should be expected as well. This is caused by the lower energy content of biodiesel.

The fuel system lines may also need to be changed if biodiesel is used. This is because biodiesel degrades certain types of rubber (See Appendix D for biodiesel material compatibility issues). This is a relatively inexpensive modification that could reduce problems later on.

APPENDICES

Appendix A - Finances

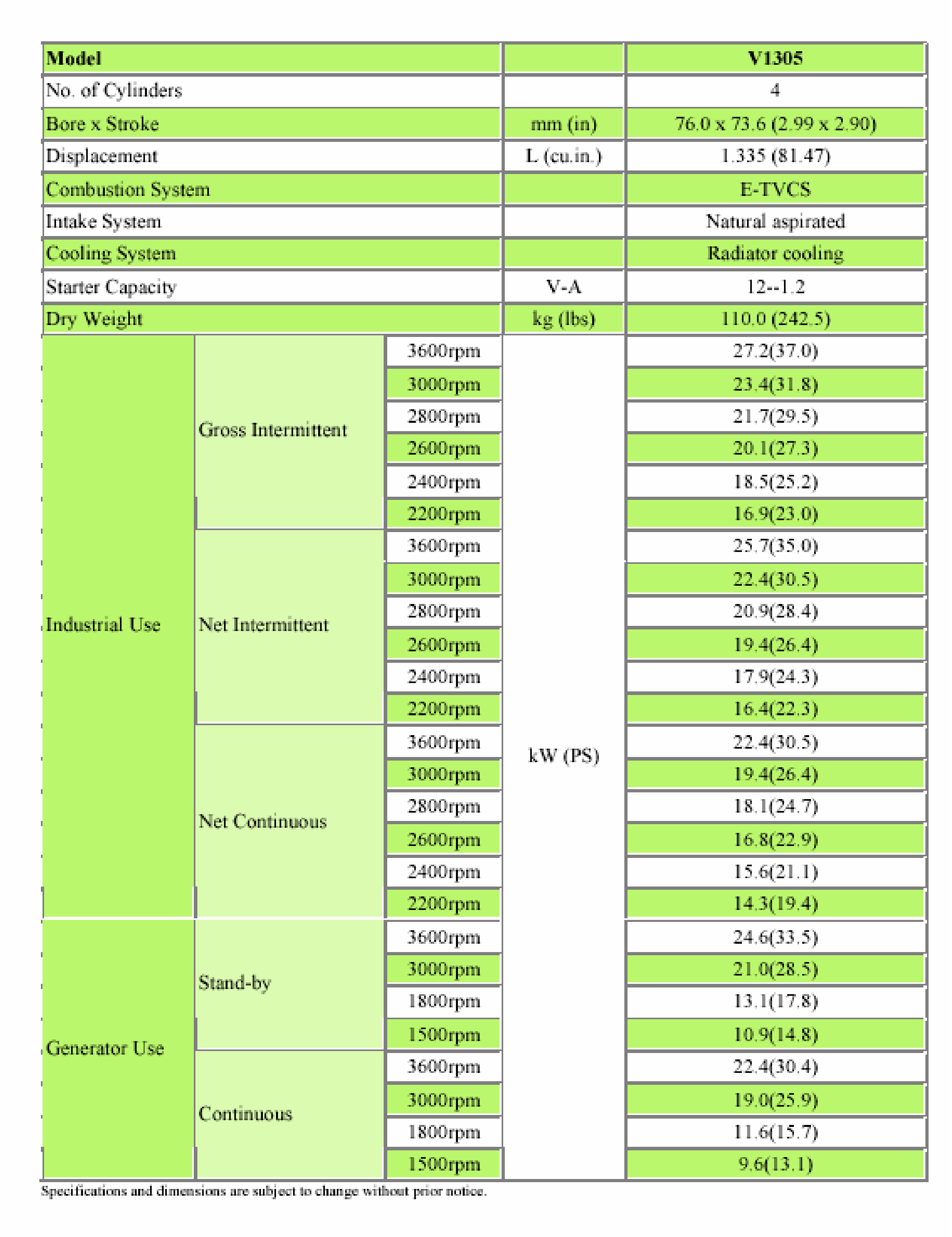
List of expenditures as of April 20, 2004

Item	Cost	Paid By	Expense Claim Submitted
Engine to Dyno Frame	$ 641.20	Chris	Yes
Misc. - Canadian Tire	$ 8.40	Chris	?
Hoses & Fittings	$ 66.43	Dave	Yes
Rubber Mat	$ 22.78	Dave	Yes
Rubber Grometts	$ 18.84	Dave	Yes
Misc. - Canadian Tire	$ 109.16	Dave	Yes
Cable. - Canadian Tire	$ 18.56	Dave	?
Hoses & Fittings- Greenline	$ 23.68	Dave	?
Engine to Dyno Housing	$ 200.38	Jeff	Yes
Flywheel to Dyno Adapter Plate	$ 217.55	Jeff	Yes
Kubota Parts	$ 374.00	Jeff	Yes
Fasteners - Fastenal	$ 23.88	Jeff	Yes
Fasteners - HH	$ 4.59	Jeff	Yes
Fasteners - HH	$ 6.67	Jeff	Yes
Fasteners - HH	$ 2.39	Jeff	Yes
Grommets - HH	$ 13.56	Jeff	Yes
Fasteners - Fastenal	$ 11.64	Jeff	Yes
Electrical - Radio Shack	$ 10.28	Jeff	Yes
Cable - Bike Kitchen	$ 7.70	Jeff	Yes
Electrical - Canadian Tire	$ 14.16	Jeff	No
Fuel - Canadian Tire	$ 9.99	Jeff	No
Total	$1,805.84		

Funding Available	Amount
IPF	$2,000.00
Mech 456	$ 50.00
Total	$2,050.00

Account Balance	$ 244.16

Appendix B - Engine Specifications

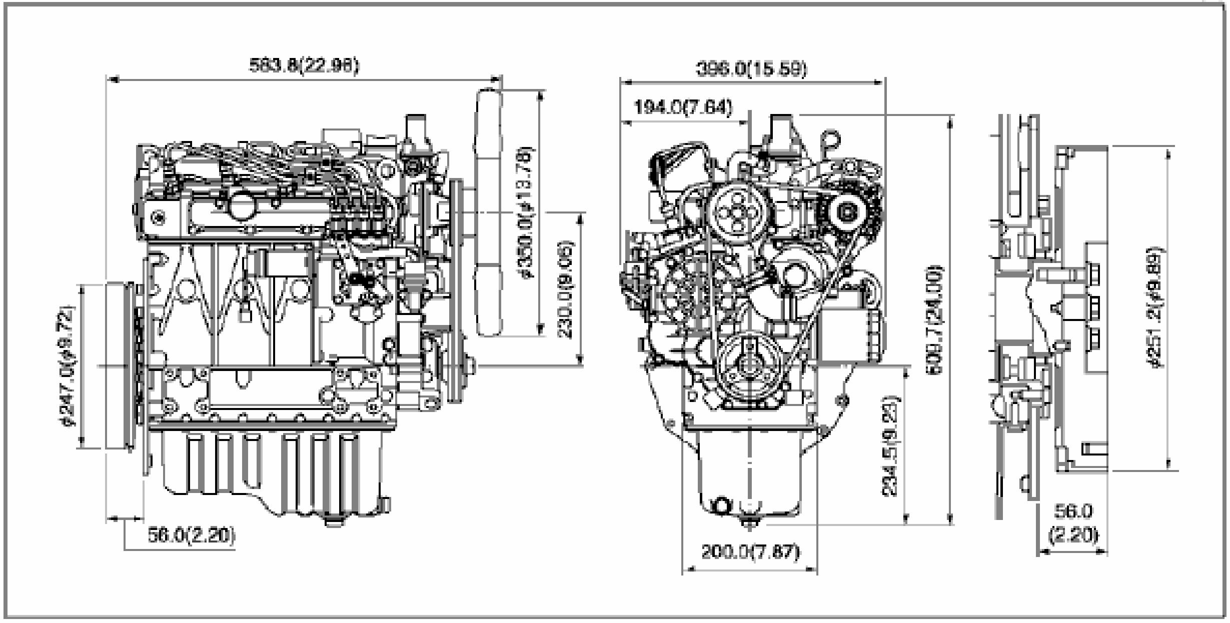


Model				**V1305**
No. of Cylinders				4
Bore x Stroke			mm (in)	76.0 x 73.6 (2.99 x 2.90)
Displacement			L (cu.in.)	1.335 (81.47)
Combustion System				E-TVCS
Intake System				Natural aspirated
Cooling System				Radiator cooling
Starter Capacity			V-A	12--1.2
Dry Weight			kg (lbs)	110.0 (242.5)
Industrial Use	Gross Intermittent	3600rpm	kW (PS)	27.2(37.0)
		3000rpm		23.4(31.8)
		2800rpm		21.7(29.5)
		2600rpm		20.1(27.3)
		2400rpm		18.5(25.2)
		2200rpm		16.9(23.0)
	Net Intermittent	3600rpm		25.7(35.0)
		3000rpm		22.4(30.5)
		2800rpm		20.9(28.4)
		2600rpm		19.4(26.4)
		2400rpm		17.9(24.3)
		2200rpm		16.4(22.3)
	Net Continuous	3600rpm		22.4(30.5)
		3000rpm		19.4(26.4)
		2800rpm		18.1(24.7)
		2600rpm		16.8(22.9)
		2400rpm		15.6(21.1)
		2200rpm		14.3(19.4)
Generator Use	Stand-by	3600rpm		24.6(33.5)
		3000rpm		21.0(28.5)
		1800rpm		13.1(17.8)
		1500rpm		10.9(14.8)
	Continuous	3600rpm		22.4(30.4)
		3000rpm		19.0(25.9)
		1800rpm		11.6(15.7)
		1500rpm		9.6(13.1)

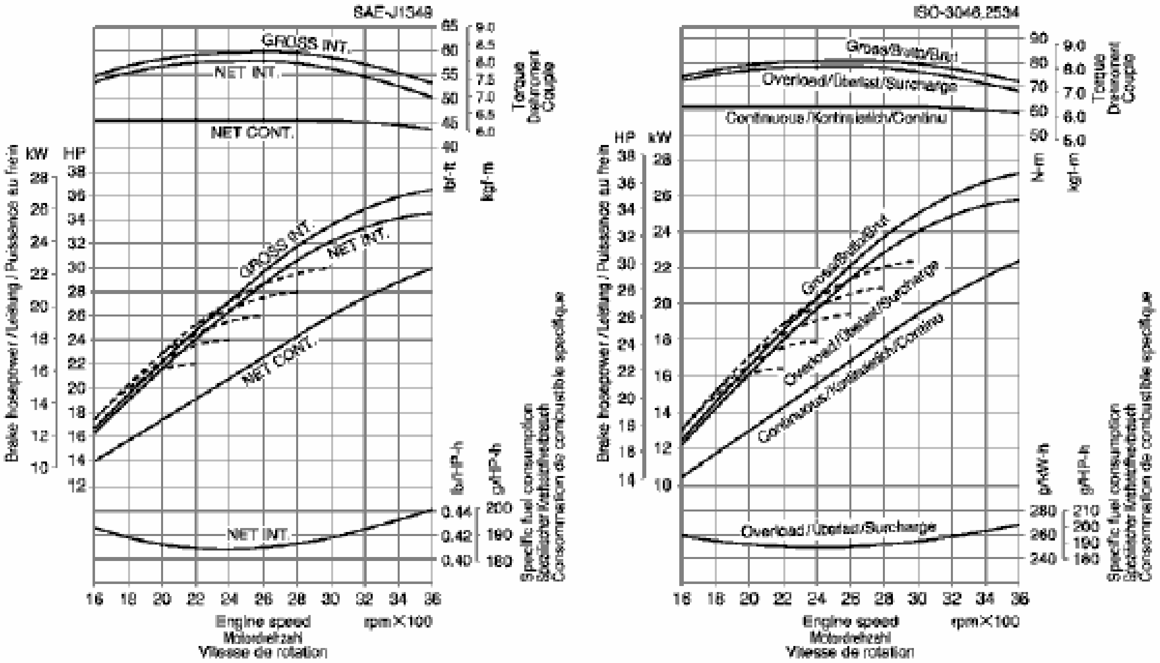
Specifications and dimensions are subject to change without prior notice.

Dimensions

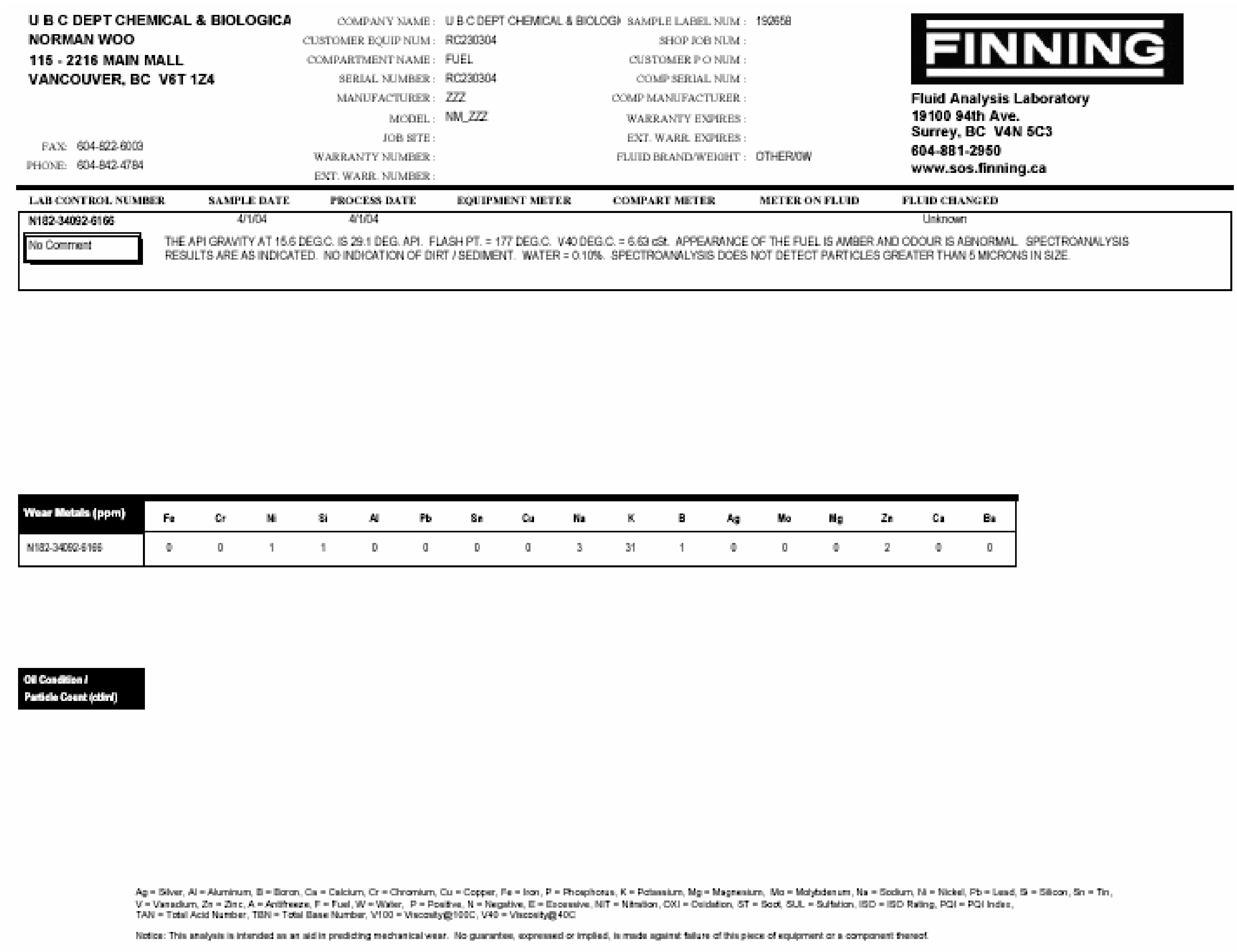
MODEL: V1305



Performance Curve



Appendix C – UBC Biodiesel Analysis



U B C DEPT CHEMICAL & BIOLOGICA
NORMAN WOO
115 - 2216 MAIN MALL
VANCOUVER, BC V6T 1Z4

FAX: 604-822-6003
PHONE: 604-842-4784

COMPANY NAME : U B C DEPT CHEMICAL & BIOLOGI
CUSTOMER EQUIP NUM : RC230304
COMPARTMENT NAME : FUEL
SERIAL NUMBER : RC230304
MANUFACTURER : ZZZ
MODEL : NM_ZZZ
JOB SITE :
WARRANTY NUMBER :
EXT. WARR. NUMBER :

SAMPLE LABEL NUM : 192658
SHOP JOB NUM :
CUSTOMER P O NUM :
COMP SERIAL NUM :
COMP MANUFACTURER :
WARRANTY EXPIRES :
EXT. WARR. EXPIRES :
FLUID BRAND/WEIGHT : OTHER/0W

FINNING

Fluid Analysis Laboratory
19100 94th Ave.
Surrey, BC V4N 5C3
604-881-2950
www.sos.finning.ca

LAB CONTROL NUMBER	SAMPLE DATE	PROCESS DATE	EQUIPMENT METER	COMPART METER	METER ON FLUID	FLUID CHANGED
N182-34092-6166	4/1/04	4/1/04				Unknown

No Comment

THE API GRAVITY AT 15.6 DEG.C. IS 29.1 DEG. API. FLASH PT. = 177 DEG.C. V40 DEG.C. = 6.63 cSt. APPEARANCE OF THE FUEL IS AMBER AND ODOUR IS ABNORMAL. SPECTROANALYSIS RESULTS ARE AS INDICATED. NO INDICATION OF DIRT / SEDIMENT. WATER = 0.10%. SPECTROANALYSIS DOES NOT DETECT PARTICLES GREATER THAN 5 MICRONS IN SIZE.

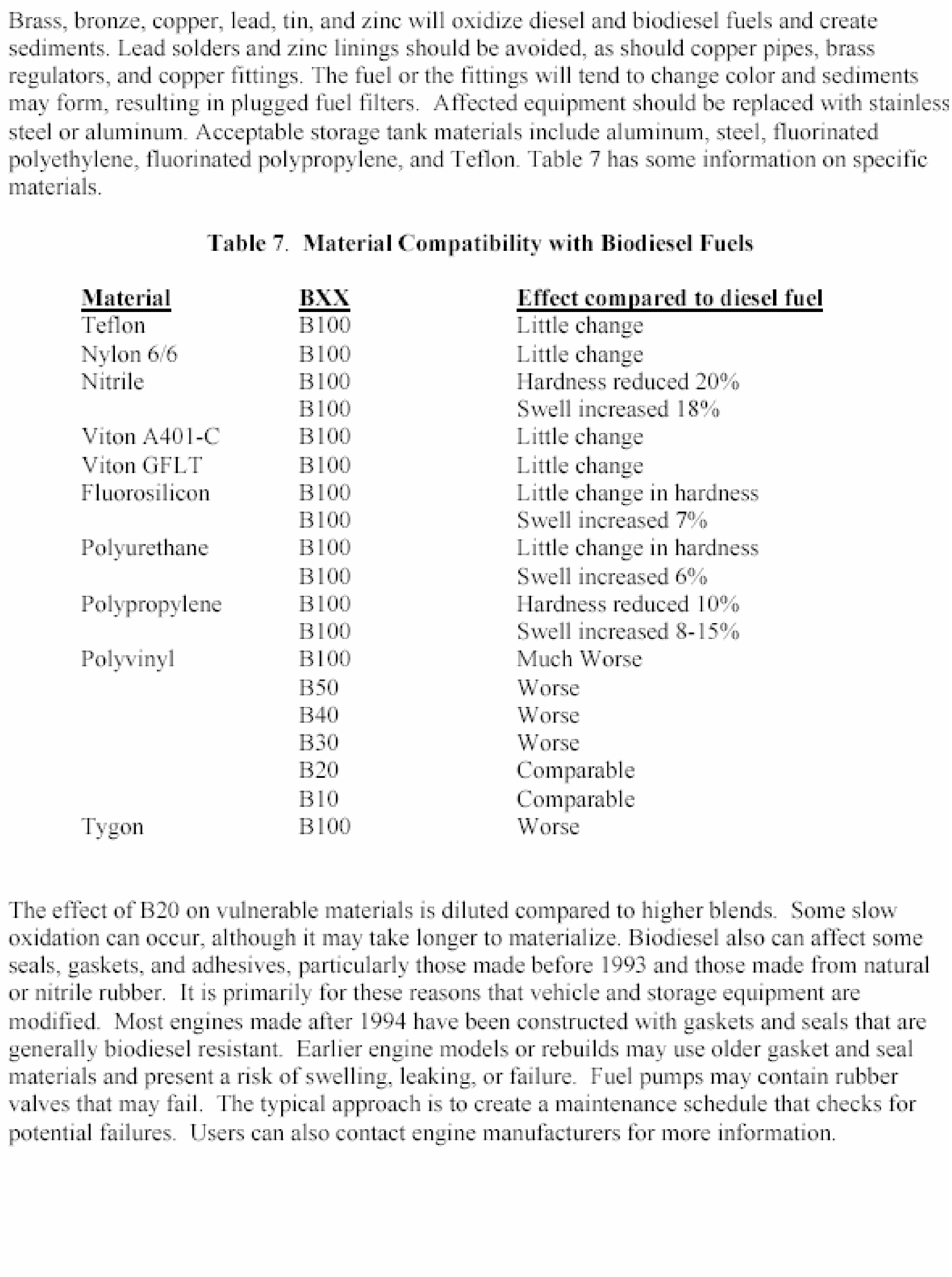
Wear Metals (ppm)	Fe	Cr	Ni	Si	Al	Pb	Sn	Cu	Na	K	B	Ag	Mo	Mg	Zn	Ca	Ba
N182-34092-6166	0	0	1	1	0	0	0	0	3	31	1	0	0	0	2	0	0

Oil Condition / Particle Count (ct/ml)

Ag = Silver, Al = Aluminum, B = Boron, Ca = Calcium, Cr = Chromium, Cu = Copper, Fe = Iron, P = Phosphorus, K = Potassium, Mg = Magnesium, Mo = Molybdenum, Na = Sodium, Ni = Nickel, Pb = Lead, Si = Silicon, Sn = Tin, V = Vanadium, Zn = Zinc, A = Antifreeze, F = Fuel, W = Water, P = Positive, N = Negative, E = Excessive, NIT = Nitration, OXI = Oxidation, ST = Soot, SUL = Sulfation, ISO = ISO Rating, PQI = PQI Index, TAN = Total Acid Number, TBN = Total Base Number, V100 = Viscosity@100C, V40 = Viscosity@40C

Notice: This analysis is intended as an aid in predicting mechanical wear. No guarantee, expressed or implied, is made against failure of this piece of equipment or a component thereof.

Appendix D – Biodiesel Material Compatibility[7]



Brass, bronze, copper, lead, tin, and zinc will oxidize diesel and biodiesel fuels and create sediments. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change color and sediments may form, resulting in plugged fuel filters. Affected equipment should be replaced with stainless steel or aluminum. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. Table 7 has some information on specific materials.

Table 7. Material Compatibility with Biodiesel Fuels

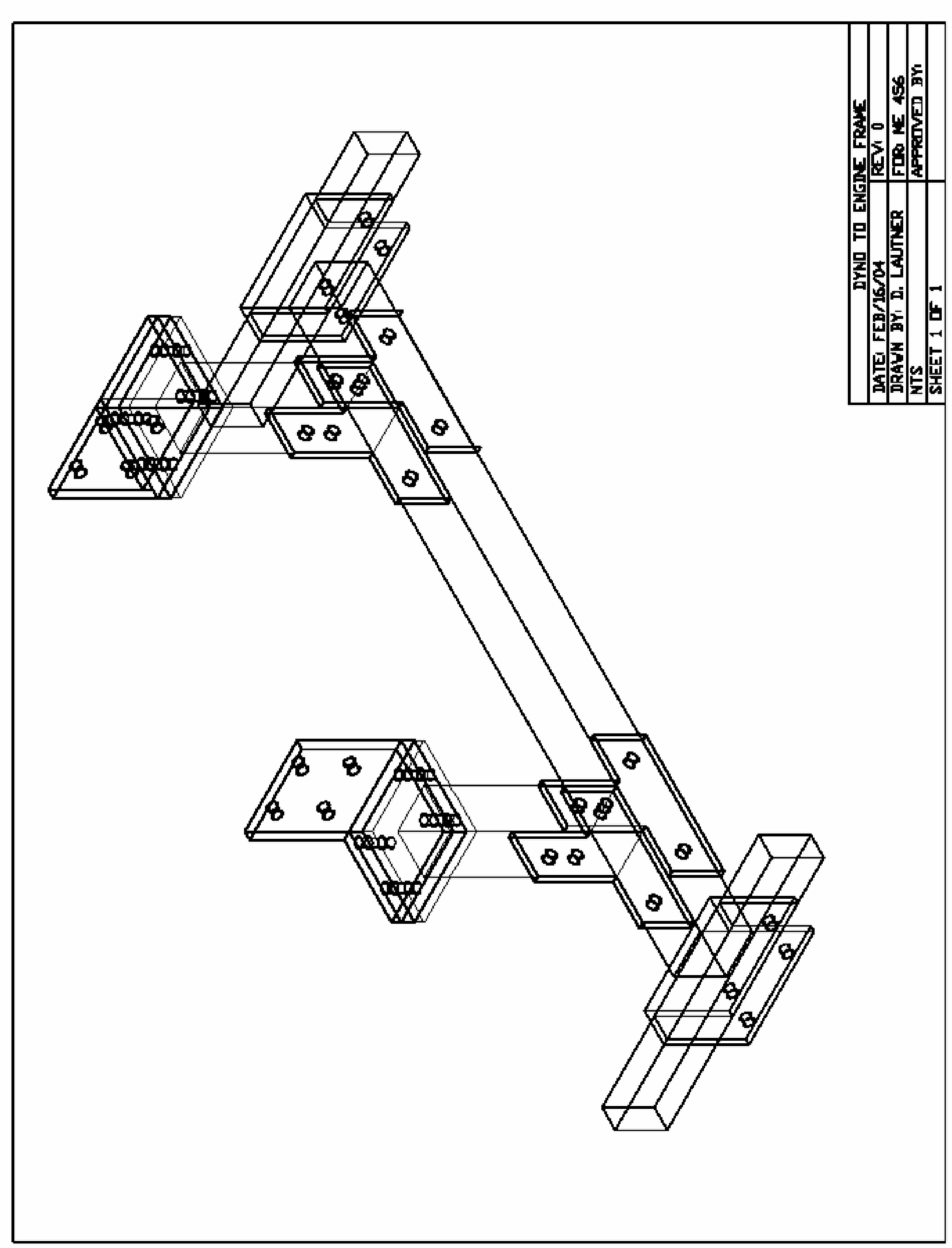
Material	BXX	Effect compared to diesel fuel
Teflon	B100	Little change
Nylon 6/6	B100	Little change
Nitrile	B100	Hardness reduced 20%
	B100	Swell increased 18%
Viton A401-C	B100	Little change
Viton GFLT	B100	Little change
Fluorosilicon	B100	Little change in hardness
	B100	Swell increased 7%
Polyurethane	B100	Little change in hardness
	B100	Swell increased 6%
Polypropylene	B100	Hardness reduced 10%
	B100	Swell increased 8-15%
Polyvinyl	B100	Much Worse
	B50	Worse
	B40	Worse
	B30	Worse
	B20	Comparable
	B10	Comparable
Tygon	B100	Worse

The effect of B20 on vulnerable materials is diluted compared to higher blends. Some slow oxidation can occur, although it may take longer to materialize. Biodiesel also can affect some seals, gaskets, and adhesives, particularly those made before 1993 and those made from natural or nitrile rubber. It is primarily for these reasons that vehicle and storage equipment are modified. Most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant. Earlier engine models or rebuilds may use older gasket and seal materials and present a risk of swelling, leaking, or failure. Fuel pumps may contain rubber valves that may fail. The typical approach is to create a maintenance schedule that checks for potential failures. Users can also contact engine manufacturers for more information.

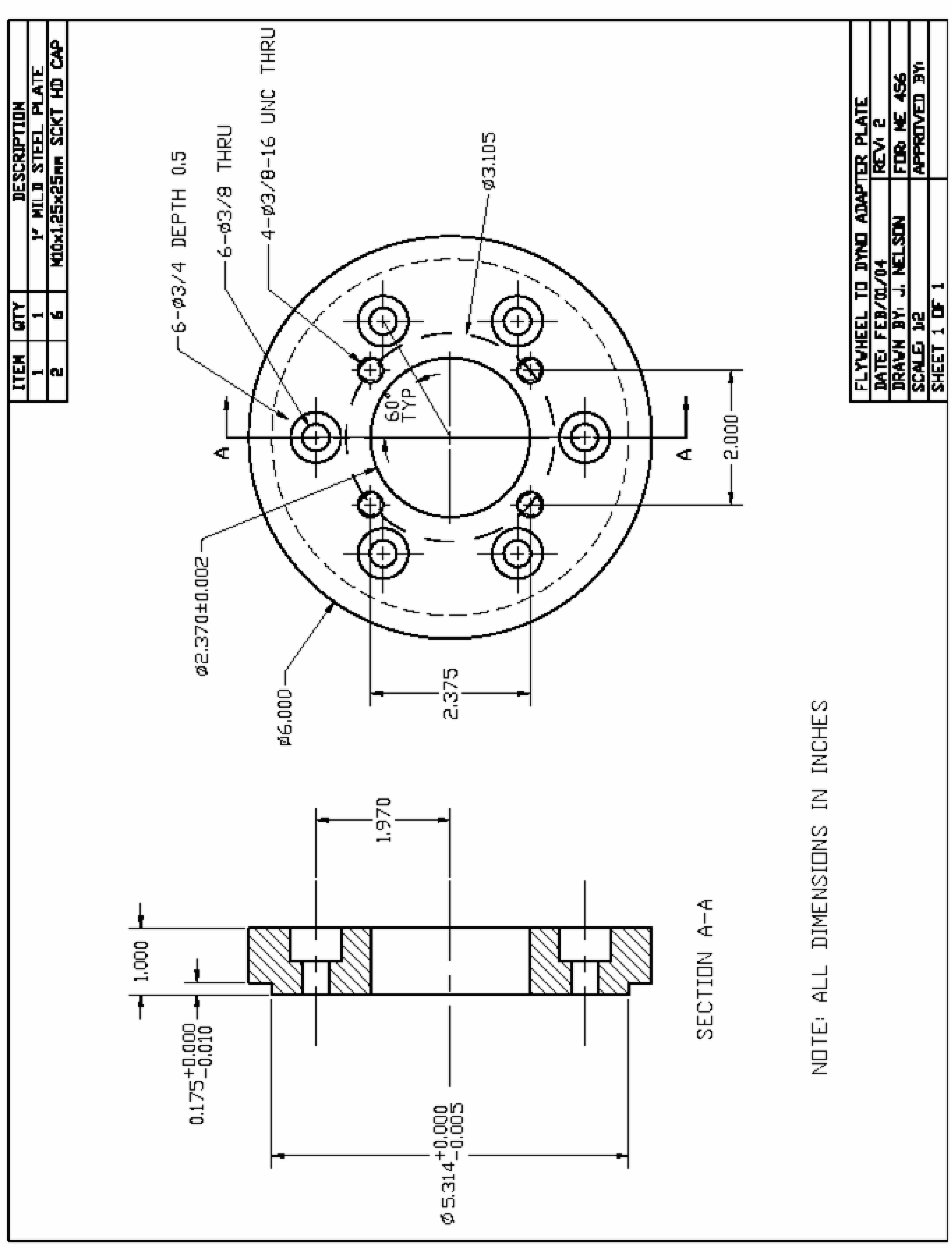
---

[7] Tyson , Shaine K. Biodiesel Handling and Use Guidelines. National Renewable Energy Laboratory Report # NREL/TP-580-30004, 2001

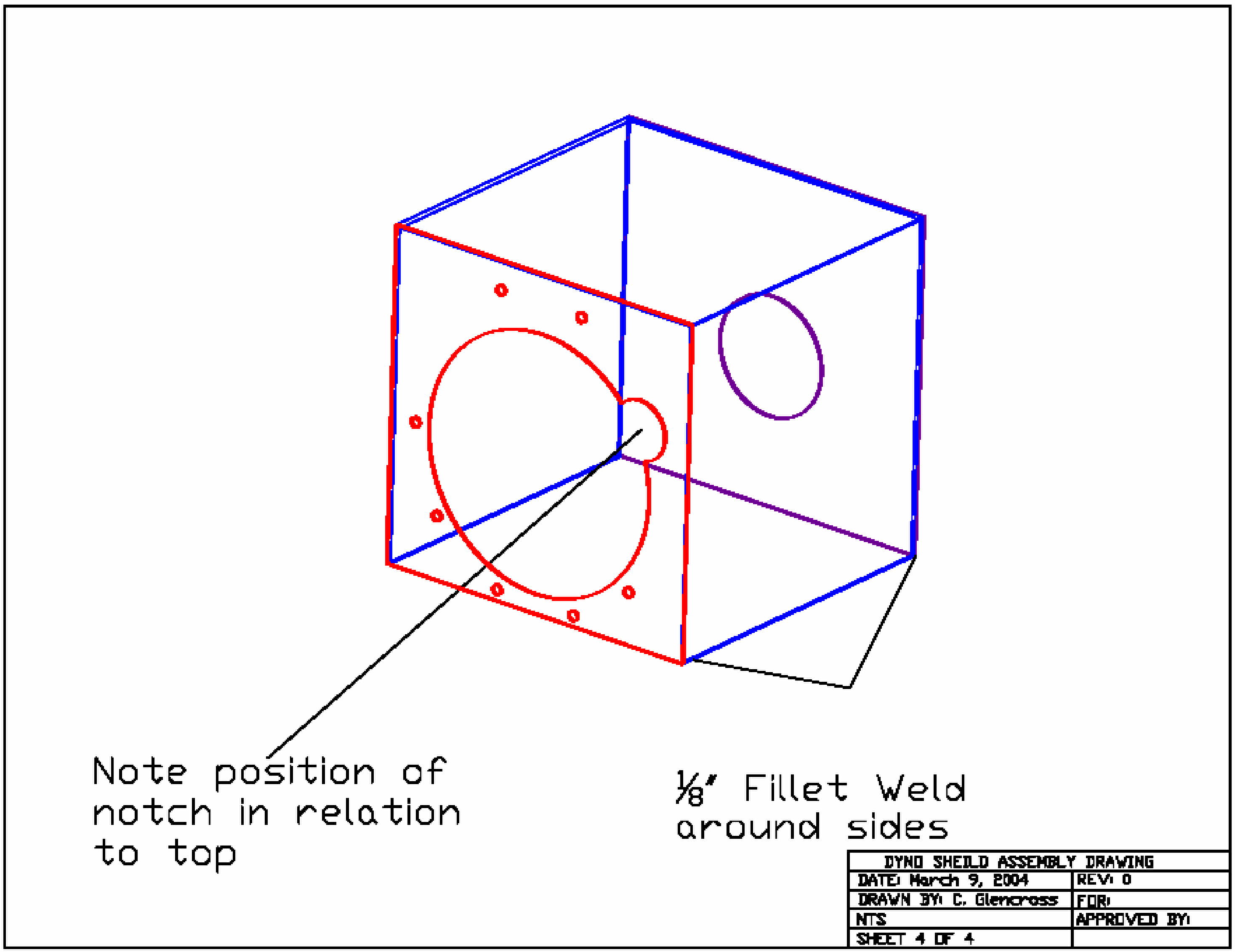
Appendix E – Engine Stand Drawing



Appendix F – Adapter Plate Drawing



Appendix G – Bell Housing Drawing



Note position of notch in relation to top

⅛″ Fillet Weld around sides

Appendix H – Sample Calculations

Torque

Linear equation from calibration = -18.537 [Nm/V]* Voltage [V] + 0.7057 [Nm]

Uncorrected Torque = -18.537 [Nm/V]* Voltage [V] + 0.7057 [Nm]
= -18.537 [Nm/V]* (-4.5042) [V] + 0.7057 [Nm]
= 84.2 Nm

Vapour Pressure = (6.1078*$10^{(7.5*\text{Temperature (oC)}}$/(237.3+Temperature (oC)))*29.529988/1000)* Relative Humidity (%)/100
= (6.1078*$10^{(7.5*20.3\text{ (oC)}}$/(237.3 + 20.3 (oC)))*29.529988/1000)* 40.5 (%)/100
= 0.285 inHg

SAE Correction Factor = 29.38 / (Barometric Pressure (inHg) -Vapour Pressure (inHg))*SQRT((Temperature (oF)+459.7)/536.7)
= 29.38 / (29.55 (inHg) -0.285 (inHg))*SQRT((68.54 (oF)+459.7)/536.7)
= .996

Corrected Torque = SAE Correction Factor * Uncorrected Torque [Nm]
= .966 * 84.2 [Nm] = 83.86 [Nm]

RPM

RPM = Voltage [V] * 1000 [RPM/V]
= 1.5994 [V] * 1000 [RPM/V] = 1599.4 RPM

Power

Power (hp) = (2 * π * corrected torque [Nm] * RPM/60)/1000
= (2 * π * 83.86 [Nm] * 1599.4/60)/1000 = 14.45 Hp

Fuel weight

Linear equation from calibration = 3.0672 [Kg/V]* Voltage [V] - 0.0037 [Kg]

Wieght of Fuel = 3.0672 [Kg/V]* 2.6785 [V] - 0.0037 [Kg]
= 8.2118 Kg