Biodiesel Engine Testing

MECH-457 Final Report

Submitted to
Jon Mikkelsen

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Darren Schwartz
Leif Norrgard
Mathew Christensen
Sean Hearle

Abstract

The Chemical Engineering Department at UBC has begun producing biodiesel fuel from waste cooking oils acquired from campus kitchens. Using methanol and a base catalyst, glycerol can be separated from the oil, leaving a mixture of methyl esters that can be combusted in compression ignition engines.

This project is concerned with testing the UBC biodiesel in a four-cylinder, 30 hp Kubota engine (V1305). This engine was chosen because it is used in several pieces of Plant Operations' equipment and provides insight into how biodiesel will perform in their engines.

Performance tests and fuel consumption tests were performed on diesel, biodiesel (B100), and a mixture of 20% biodiesel - 80% diesel (B20). The B100 exhibited approximately a 5% reduction in power across the entire speed range, and a 17% increase in fuel flow rate. This results in a 25% increase in specific fuel consumption and a decrease in thermal efficiency from 29.6% using diesel to 28.8% using biodiesel. These results are expected due to the lower energy content of biodiesel fuel.

There was greater interest in the performance of B20 than in B100 because B20 is the mixture that Plant Operations will be running, and this experiment is partially for their benefit. There was no distinguishable difference in power output between B20 and diesel. Specific fuel consumption is 6.8% higher for B20, which leads to a thermal efficiency of 28.3%. This is lower than that of B100 because the lower energy content of B100 brings up its efficiency.

Recommendations are provided for work that future groups should consider. A CD containing electronic copies of all relevant information, articles, and drawings has been included for the convenience of future groups.

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1 Introduction

The purpose of this MECH-457 project is to design and build an engine test cell to be used for the evaluation of UBC's biodiesel. This biodiesel is produced by Norman Woo of the UBC Chemical Engineering department under the supervision of Dr. Naoko Ellis. Current capacity is approximately 300 liters per day, with the potential for up to 1000 liters per day. Several production methods exist; the one used by UBC being a base catalyzed transesterification process. The feedstock for the process is waste cooking oil collected from campus kitchens, methanol, and potassium hydroxide as a catalyst. At this stage, the end user is UBC Plant operations, who blend 20% biodiesel to 80% regular #2 diesel (designated B20 fuel).

Bio-fuel has been around since the invention of the engine, but has not gained wide acceptance due to the relatively low cost and availability of petroleum diesel fuel. Considering the current world energy situation, this may not be the case for long. Biodiesel is gaining momentum as an alternative renewable fuel, but certain concerns must be addressed before equipment owners, manufacturers, and the general public fully accepts it.

Mechanical reliability is the most notable concern. The increased lubricity of biodiesel is a benefit to fuel pumps and overall engine wear. The uncertainty lies with the formation of hard deposits that may form on fuel injector tips[1] and piston rings[2]. This phenomenon has been noted in several studies, and is highly dependent on the engine, biodiesel feedstock, and production method.

Lubricating oil dilution by fuel is another concern that may lead to premature wear and failure of an engine. This makes it necessary to quantify the dilution rate so that measures can be taken to mitigate the effects.

This project is concentrated on optimizing the test stand setup and conducting preliminary power and fuel consumption tests on diesel fuel, B20 and B100. The initial goal was to conduct extended-operation reliability tests and inspections, but due to time and dynamometer scheduling constraints, this will have to wait for future tests. Requirements for future test work are discussed in the recommendations section.

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[1] Sem, Thomas R. 2004. Investigation of Injector Tip Deposits on Transport Refrigeration Units Running on Biodiesel Fuel. SAE Technical Paper 2004-01-0091. (see appendix F).

[2] Sem, Thomas R. 2004. Effect of Various Lubricating Oils on Piston Deposits in Biodiesel Fueled Engines. SAE Technical Paper 2004-01-0098. (see appendix G).

2 Test Apparatus

Several components had to be fabricated in order to run the Kubota engine on a dynamometer designed for a much larger Chevrolet engine. The main components include: a bell housing, a power transmission shaft, engine stands, and various exhaust and cooling adapters.

2.1 Bell Housing

It is necessary to rigidly connect the power absorbing water pump of the dynamometer to the engine. The water pump is suspended by a coil of heavy cable designed to allow some movement, but it is not designed to hold the water pump stationary during engine operation. The bell housing aligns the water pump to the output shaft of the engine, and transmits the reaction torque back through the engine and stand.

A bell housing was constructed by a previous group, but it did not properly align the engine and water pump. The resulting vibration due to shaft misalignment caused damage to the bell housing. Because of this, it was decided to construct another bell housing. Carmanah Design and Manufacturing Inc. located in Vancouver generously donated the materials and machine shop time for the housing. Drawings of the housing can be found in Appendix E. Figure 1 below shows the housing installed.

Figure 1: Bell Housing Installed

The bell housing was constructed from a section of 10” pipe x 0.25” thick with two 0.375” thick plates welded to the ends. A flywheel locating ring was temporarily welded inside the engine side of the housing and machined to fit tightly over the flywheel and maintain concentricity. The dynamometer side also had a concentric hole machined in it for alignment with a locating step on the dyno. This allowed the dynamometer water pump to be concentrically aligned to the engine flywheel. With the housing and engine aligned, two holes for dowel pins were reamed in the engine flange in order to maintain alignment and aide in installation of the housing. Several clearance holes were made for mounting bolts then the flywheel locating ring was removed.

2.2 Power Transmission Shaft

The flywheel of the engine must be connected to the water pump of the dynamometer in order to transmit torque. To do this, two short shafts with appropriate flanged ends were designed and constructed. The two shafts were connected using a Lovejoy L150 flexible coupling. The coupling is meant to alleviate any rotational vibration from slight shaft misalignment. Drawings of the shafts can be found in Appendices C and D. One inch long keys made of mild steel were used to constrain the shafts and coupling together. These keys will shear at a torque much lower than what the dynamometer is rated for, but higher than the maximum output of the engine. The shafts were connected to the flywheel and water pump using grade 5 bolts.

After connecting the engine and dynamometer, it was found that the set screws on the coupling jaws were not sufficient to prevent the jaws from sliding down the shafts. To remedy this, two collars were machined out of thick walled 1” steel pipe and pressed onto the shafts. These collars provide a shoulder for the coupler jaws to rest on, and prevent the coupler from coming out of mesh.

2.3 Engine Stands

The engine must be connected to the frame of the dynamometer to maintain a fixed position and transmit the torque of the engine to the dynamometer test stand frame. A previous group constructed two aluminum engine stands which are being used again for this setup. It was necessary to insert some aluminum shims around the mounts on the dynamometers frame in order to properly align the engine to the frame, and achieve a tight fit. The engine stands and their installation orientation can be seen in Figure 2 below.

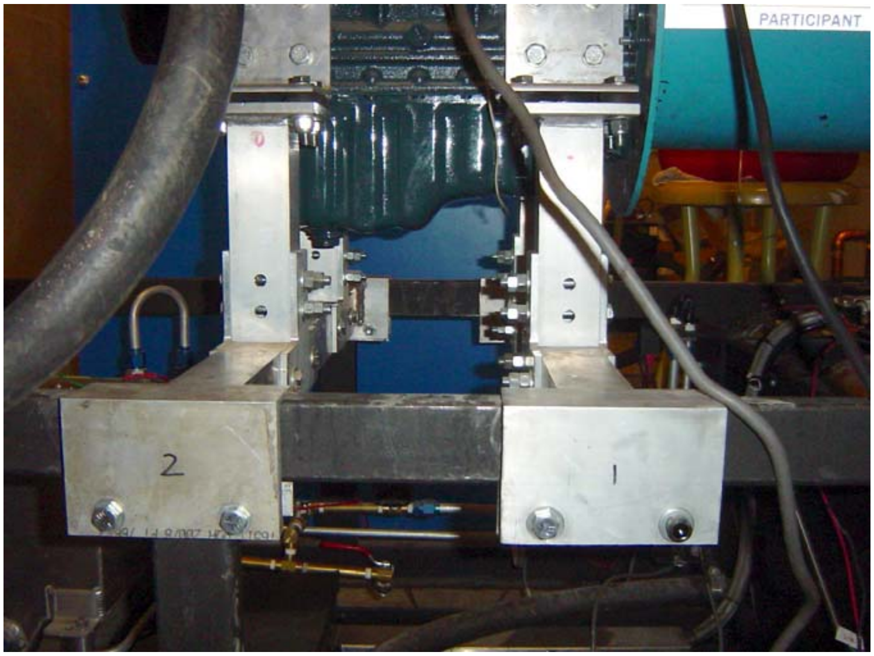

Figure 2: Engine Stands

2.4 Exhaust and Cooling Adapters

Several adapters were necessary to connect the engine exhaust and cooling system to the building exhaust duct and dyno cooling tower respectively. The inlet and outlet of the engines cooling system are both 1” ID, while the cooling tower of the dynamometer has a 1.5” inlet and 1.75” outlet. Several plumbing adapters and different hoses were used to connect the cooling system. Pictures of these adapters can be seen in figure 3 below.

Figure 3: Cooling Adapters

The engine exhaust was connected to the building exhaust system using a 3” flexible steel hose. The 1.25” exhaust of the engine was connected to the 3” flexible hose through the use of an adapter consisting of several exhaust adapters MIG welded together. This adapter can be seen in Figure 4 below.

Figure 4: Exhaust Adapter

3 Project Funding

An analysis of the project finances can be found in Appendix K. The project was funded mainly by donors and Dr. Rogak, who allotted $1000 for the test stand and testing itself. Carmanah Design and Manufacturing Inc. contributed the materials and shop time for the fabrication of the bell housing to the tune of $1550. Had the group gone to another source and had it done, the cost would have been somewhat higher due to the regular shop profit margins. Additionally, UBC Plant Operations donated about 30 dollars worth of fuel, and UBC Chemical Engineering supplied 5 gallons of biodiesel.

4 Test Plan

When this project was begun, the original plan was to be operational mid-way through the second academic term so that long term reliability testing could be done. Throughout the term, construction in and around CEME 1115D (the engine lab) and scheduling difficulties with the MECH 302 engine testing laboratory prevented operations.

The Superflow 901 dynamometer has the ability to measure many different performance evaluation criteria on an engine. The performance data can either be read manually from the control console, or with a data acquisition system and computer. Due to time constraints and problems with the data acquisition system, readings were taken by hand using the control console.

Measurements taken in this experiment were engine speed, torque output, power output and airflow. These can all be read off of the control console. Also, average fuel consumption was measured by weighing the fuel on a digital readout scale before and after extended tests.

4.1 Pre-Test Procedures

Before testing, a variety of checks and tasks must be carried out. The engine should be inspected visually for any problems, and the dynamometer should be thoroughly checked for proper operation. The necessary procedures can be found in Appendix I. Additionally, the engine should be properly warmed up prior to tests for two reasons. First, the engine can be damaged if run under high loads before reaching proper operating temperature. Second, torque, power, fuel flow and many other types of readings tend to fluctuate depending on engine temperature. Once the engine reaches operating temperature (in this case 160-170 degrees Fahrenheit cooling water temperature), the readings will be reliable.

4.2 Performance Characterization

For any long-term engine testing, it is necessary to evaluate performance characteristics before testing period to establish a good baseline. Following long term testing, the performance tests can be carried out again to ascertain whether there has been a significant degradation in the condition of the engine due to the use of a different fuel.

The Kubota performance characterization was carried out to simulate actual operating conditions. This particular engine is designed to run at or near peak RPM for entire working days under full load. Therefore, performance testing was done at wide open throttle at a variety of loading conditions. Loading was simulated by setting the dynamometer to servo-mode on the control panel. The servo function essentially applies the load required to maintain the engine at the desired speed. The Kubota will run as low as 800 RPM, but under full throttle operation, the engine struggles if it is loaded this much. Also, the internal engine speed governor is set around 3100 RPM, at which point the fuel supply is limited. As a result, at the governed speed, the engine torque output drops significantly and the engine will not rev any higher.

The speed was varied in 100 – 200 RPM increments from 1600 to 3100 then back down to 1600 using the servo control dial. The speed was varied by ramping up and then back down again to eliminate hysteresis in the measurements. Torque, power, and airflow were recorded for each speed increment. Graphs in the following section show the results of the performance characterization tests for the three different fuels.

4.3 Fuel Consumption Measurements

These tests are done to evaluate any differences in fuel consumption when the engine is running on the three different fuels. The data can also be used to evaluate the thermal efficiencies of the engine when running on each type of fuel.

The consumption tests were done by filling the fuel tank with the test fuel then weighing it with a digital scale accurate to 1 gram. The engine was then started and run at wide open throttle and loaded to 2800 RPM using the servo function. It was run for 40-60 minutes while recording torque, power, airflow, ambient temperature in the lab and relative humidity in the lab every 10 minutes. Once the engine was stopped, the fuel reservoir was weighed again to determine the total mass of fuel consumed in the test. The data is used in section 4.2 to determine brake specific fuel consumption and thermal efficiency.

4.4 Reliability Testing

Reliability testing with B20 fuel is the primary objective in this experiment. Since there was not sufficient time to carry out extended tests, this will have to be done in the future. In total, about 7 hours of testing was done using B20 fuel. Additional tests with regular diesel and neat biodiesel increased the total running time of the engine to almost 10 hours. This does not meet the original project objective of 200+ hours of B20 testing, but is a good start for future work.

The reliability testing was done under the same conditions as the fuel consumption tests. The fuel injector in cylinder #1 was inspected before and after the test work in order to evaluate whether any deposits had accumulated. Results of this are given in section 4.3

4.5 Post-test Procedures

After full-load testing, the engine should be idled-down for at least 3 minutes in order to stabilize the internal engine temperature. This can not always be done when testing fuel consumption because the dynamometer measurements fluctuate at low RPM. However, it should be done whenever possible to prolong the life of the engine. Details on shutdown procedures of the engine and dynamometer can be found in Appendix I.

5 Results

This section presents the results obtained through a total of 10 hours of testing. Torque and power results are shown, as well as fuel consumption and fuel injector inspections.

5.1 Torque and Power

The wide-open-throttle torque and power curves for diesel, B20, and B100 are shown below. Note the power axis is on the right side.

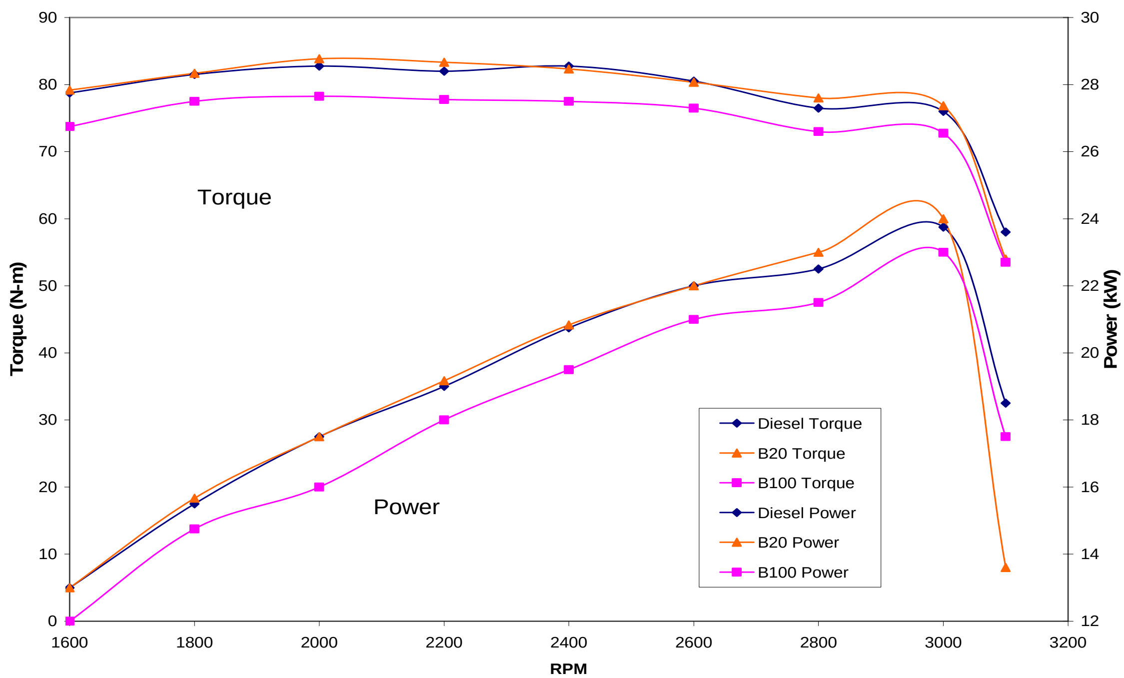

Figure 5: Comparison of Torque and Power with different Fuels

There appears to be little difference in performance between regular diesel and the B20 mixture. The B100 displays about a 5% reduction in power from diesel, actually less than the expected 10% reduction. These curves have been averaged over several runs for accuracy, and speed was varied in both directions to eliminate hysteresis error. Error bars are not shown as the error was assumed to be 0.5 units, which is too small to be visible on the graph.

The following page contains graphs of all test runs for the three different fuel blends. It can be seen that the tests are quite repeatable and will be even more accurate when automatic data acquisition is used. The manufacturer's performance curve is located in appendix A for reference.

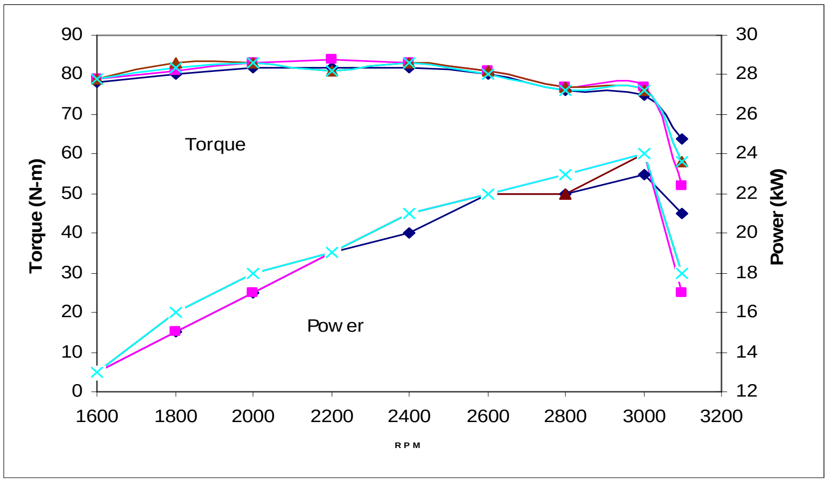

Figure 6: Regular Diesel Torque and Power Tests.

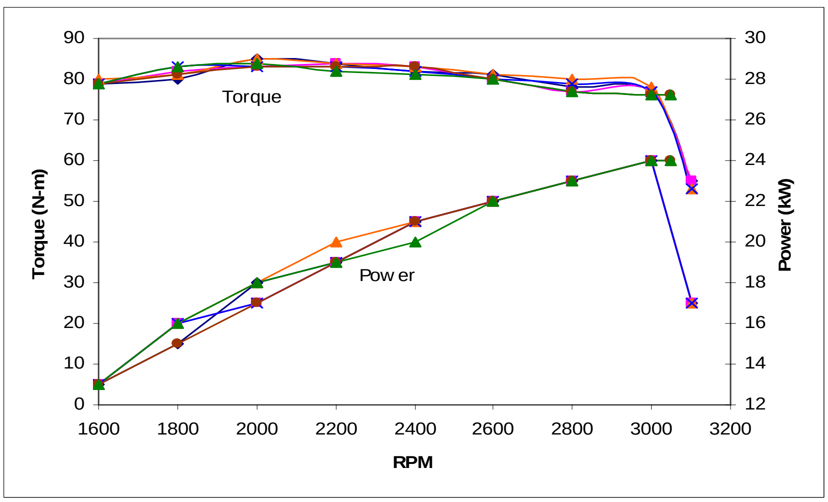

Figure 7: B20 Torque and Power Tests.

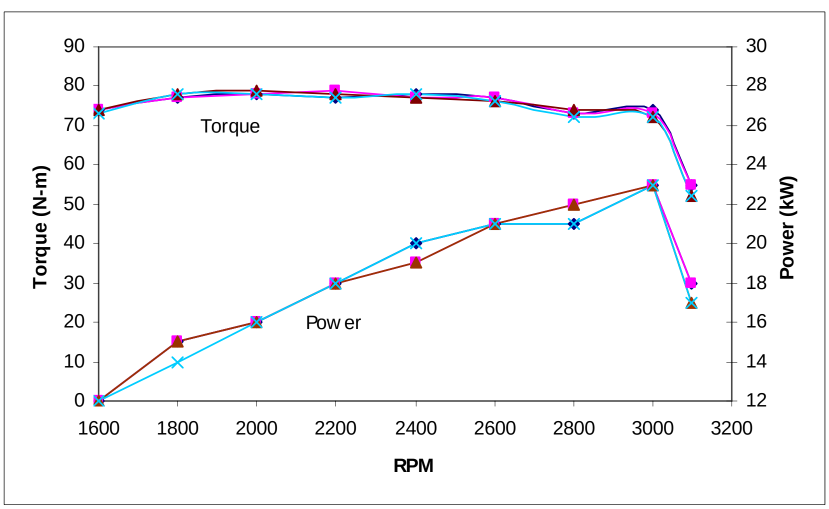

Figure 8: B100 Torque and Power Tests.

5.2 Fuel Consumption

The fuel flow rate was measured by weighing the fuel reservoir before and after a one hour wide-open-throttle test at 2800 RPM. The table below summarizes the flow rates for the different fuel blends.

Table 1: Specific Fuel Consumption of Various Fuel Blends.

Fuel	Fuel Flow Rate		Avg Power		Specific Fuel Consumption		Efficiency
Diesel	5923	g/hr	22.5	kW	263	g/kW-hr	29.6%
B20	6465	g/hr	23	kW	281	g/kW-hr	28.3%
B100	6923	g/hr	21	kW	330	g/kW-hr	28.8%

The B100 fuel has a 17% higher fuel flow rate than diesel, and a 25% higher specific fuel consumption. This means that more fuel is consumed, and less power is output. This is to be expected, as the lower heating value of biodiesel is about 10% less than that of diesel. Published heating values were used for calculations because fuel sample results are not yet available for UBC's biodiesel. For B20, the fuel flow rate is 9% higher and the specific fuel consumption is 6.8% higher than when using diesel.

The thermal efficiency is 29.6% when using diesel, is 28.8% when using neat biodiesel, and is 28.3% when using the B20 blend. Sample calculations are provided in appendix J.

5.3 Fuel Injector Tip Inspection

Figure 5 shows the tip of the fuel injector in cylinder #1 before any testing was done. Since the engine is relatively new, there is little build up aside from slight amounts of carbon on the fuel release valve (in the center). A post-test inspection of the same injector showed no observable change.

Figure 9: Fuel Injector Tip Before Testing.

6 Conclusion

The dynamometer has been configured for use with the Kubota engine and preliminary performance and fuel consumption data has been collected. As expected, the engine exhibited a decrease in output power while running with B100 biodiesel fuel. However, the decrease was lower than expected at 6.7%. The smaller than expected loss of power is partially due to the 17% increase in fuel flow rate. This is evident in biodiesel's 25% increase in specific fuel consumption. These values give a thermal efficiency of 28.8% which is 0.8% lower than that of diesel.

The tests with B20 exhibited a 9% increase in fuel flow rate and a 6.8% increase in specific fuel consumption. The lower specific fuel consumption occurs partially because there is no associated loss in power with B20, only an increase in fuel flow rate. B20 has a thermal efficiency of 28.3%, which is lower than B100. This is because B100 has lower energy content than B20.

Performance degradation over time while running biodiesel could not be detected because of the limited time available for testing. It will be important for future groups to measure this. There was no visual evidence of combustion deposits formed over this short test period.

If exhaust emission samples are to be taken in the future, a valve will have to be tapped into the exhaust manifold. This will be fairly simple, but a damper will also be required after the fitting in order to force the gasses out the sample valve. It may be possible that this can be purchased, but if not, it will require careful design so as not to allow exhaust gasses to escape into the testing room.

Future testing will benefit from more sensors and automatic data acquisition. These requirements are discussed further in the recommendations section.

7 Recommendations

Although the amount of testing desired at the beginning of the project was not obtainable, the testing that was done provides a good baseline for future work. This section presents a variety of recommendations for future work in this ongoing energy solutions project.

7.1 Data Acquisition

The performance characteristics were read manually from the dynamometer console, which proved time consuming. Automatic data acquisition would greatly improve the speed and accuracy of tests. Measurement of fuel flow rate is especially important. The flow rates taken during these tests involved weighing the fuel reservoir before and after a constant speed run. This method is time consuming and prone to error. It also prevents flow measurement during performance tests where the operation conditions are changing in time. In the future, it would be beneficial to acquire a signal from the scale and record the mass over time. This would allow the fuel flow rate to be easily synchronized with the instantaneous operating conditions. Exhaust gas temperature acquisition is also desirable.

As discussed in the following section, an in-cylinder pressure transducer would allow measurement of the ignition advance and peak cylinder pressure. It is important to determine how these values change with fuel properties and exhaust emissions. A shaft position encoder will also be required for this measurement.

7.2 Injection Timing and Ignition Timing

After an extensive literary search, it is apparent that the different physical properties of biodiesel are somewhat responsible for the increased in-cylinder temperatures that cause NOx formation. These properties manifest themselves differently depending on the design of the fuel injection system. Tat and Van Gerpen[3] wrote a report worthy of review before continuing research in this area. In it they note that the higher speed of sound in biodiesel causes the pressure pulse to travel faster from the fuel pump to the injector. This results in an earlier injection, the amount of which is dependent on the length of the fuel line. For this reason, the pump-line-nozzle injection system of this Kubota engine is more sensitive to the effect than a mechanical unit type injector that has no high-pressure lines between the pump and injector. The higher bulk modulus of biodiesel is responsible for a faster pressure rise in the fuel, and is dependent on the volume of fuel being pressurized. This also contributes to early injection. The generally higher cetane number of biodiesel also allows it to ignite more quickly.

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[3] Tat, M.E. and Van Gerpen, J.H. 2003. Measurement of Biodiesel Speed of Sound and Its Impact on Injection Timing. NREL Subcontractor Report. (NREL/SR-510-31462)

A combination of these effects can advance the ignition timing by as much as 4° of crank rotation[4]. It is well documented that NOx formation increases with peak cylinder pressure. Advanced ignition timing raises the peak cylinder pressure, and hence forms more NOx. If future test work is to focus on exhaust emissions, it would be interesting to retard the timing of the injection pump in order to bring the ignition point closer to the engine's design operating point. This will require the purchase of an in-cylinder pressure transducer in order to measure the point of peak cylinder pressure and its magnitude. This data could then be correlated with emission test data.

7.3 Combustion Deposit Formation

Time constraints did not allow extended operation of the engine as planned. This prevented the acquisition of combustion deposit information. Future work should include longer runtimes in order to observe this effect.

Literature suggests that the cause of these deposits may be the larger fuel droplet sizes associated with biodiesel. Fuel droplet size is a function of surface tension, density and viscosity. Since the viscosity of biodiesel is higher than diesel, the fuel droplets are larger and hence may not be fully burned. The remaining biodiesel may then decompose at high temperatures (430-480°C)[5] and form the deposits. The viscosity of UBC biodiesel is highly dependent on temperature. Quantitative testing on the viscosity of biodiesel was not conducted, but it was noted that during initial startup, the fuel was quite syrupy. After some operation, the fuel tank became quite warm due to fuel recirculation through the injector manifold. The viscosity of the biodiesel decreased dramatically at this temperature.

In the future, it may be necessary to preheat the fuel to ensure the fuel properties remain constant throughout the test. This may have the added benefit of improving combustion due possibly smaller fuel droplets. If biodiesel is to become a viable replacement for diesel fuel, it will also have to be capable of cold weather operation. Currently, biodiesel tends to gel around 0°C. For this reason, preheating the fuel may become a necessary step in biodiesel usage, regardless of this viscosity control effect. Perhaps a small reservoir of fuel could be electrically heated on the same circuit as the glow plugs for starting; then after starting, waste heat from the engine could preheat the main fuel tank.

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[4] Szybist, James P. and Boehman, Andre L. 2003. Behavior of a Diesel Injection System with Biodiesel Fuel. SAE Technical Paper 2003-01-1039

[5] Sem, Thomas R. 2004. Effect of Various Lubricating Oils on Piston Deposits in Biodiesel Fueled Engines. SAE Technical Paper 2004-01-0098. (see appendix G).

7.4 Engine oil dilution

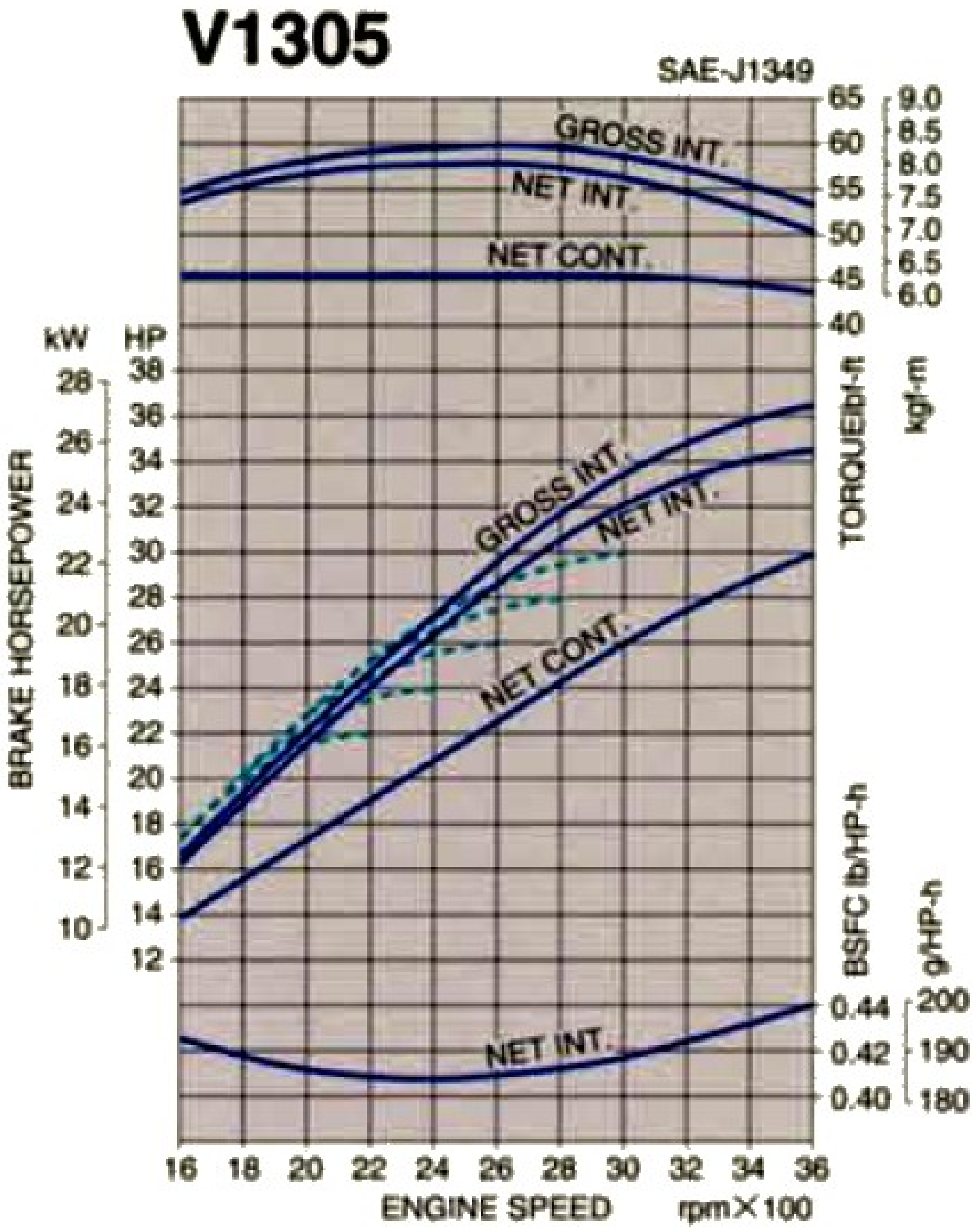
Studies have noted that engine lubricating oil tends to become diluted with fuel more quickly when running biodiesel instead of diesel[5]. Most manufacturers recommend doubling the oil change frequency when using biodiesel.

It was planned to periodically test the viscosity of the engine oil over the course extended operation. Again, time constraints prevented these long runtimes, so this should be done in future tests. It has been suggested that the reason for this is related to the larger fuel droplet size and incomplete burning of biodiesel. Remaining fuel may find its way past the piston rings and into the oil pan. Biodiesel is also a better solvent than diesel, so this may also play a role in the oil dilution rate. Regardless of the cause, the dilution rate should be quantified.

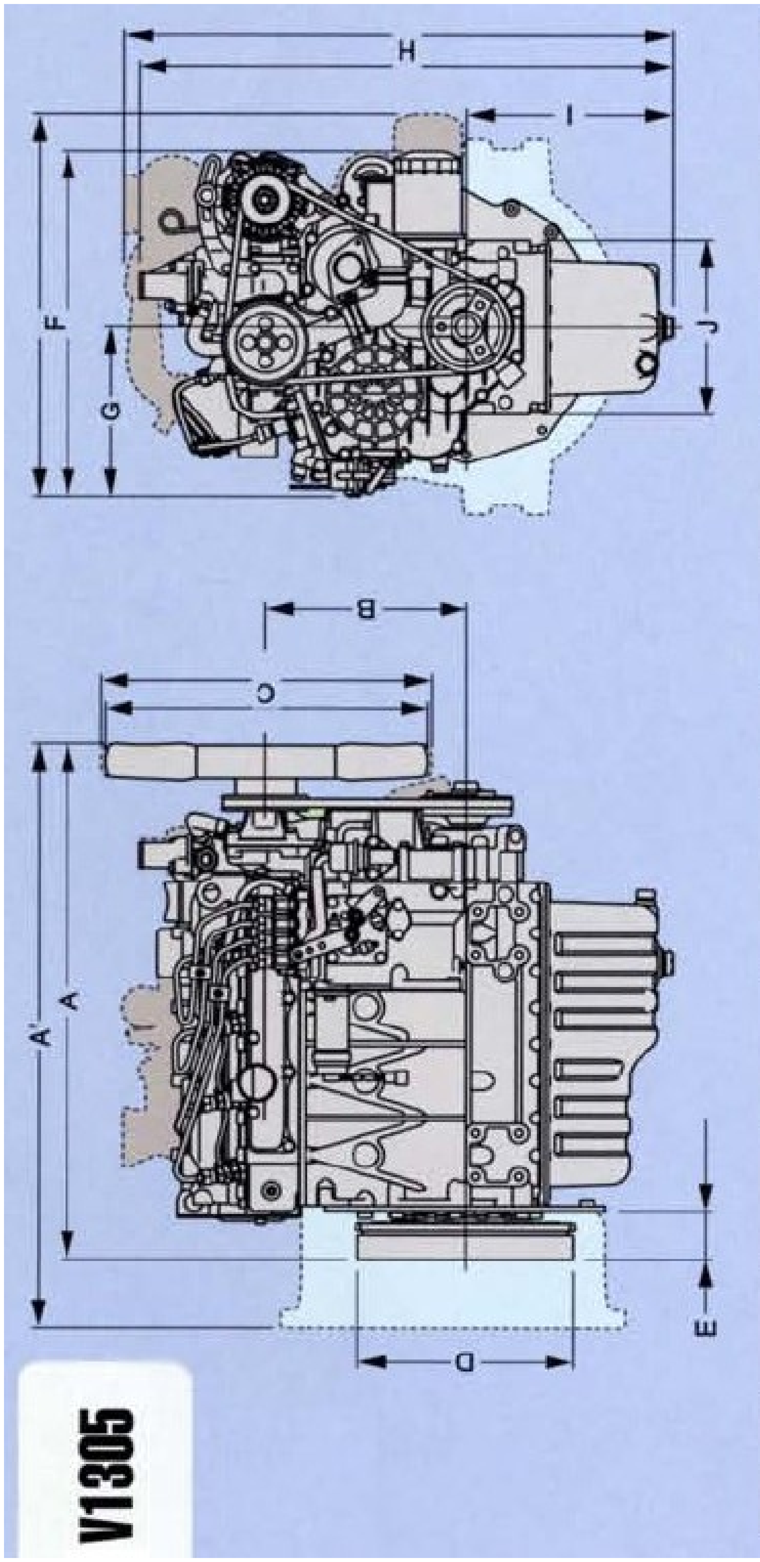
7.5 Final Notes

Since compression ignition engines are designed and tuned for use with diesel fuel, it seems logical that fuels with different properties, such as biodiesel, may require some engine adjustment in order to combust optimally. The most likely manifestation of non-optimal burning is increased NOx emissions. Mitigation of this may be as simple as retarding the fuel injection timing slightly. It should be noted that these effects are engine dependent, and some engines may require no adjustment at all. Another option is to use fuel additives that bring the relevant properties of biodiesel closer to those of diesel. This is speculation only and requires further testing to be verified.

Appendix A - Manufacturer's Test Data

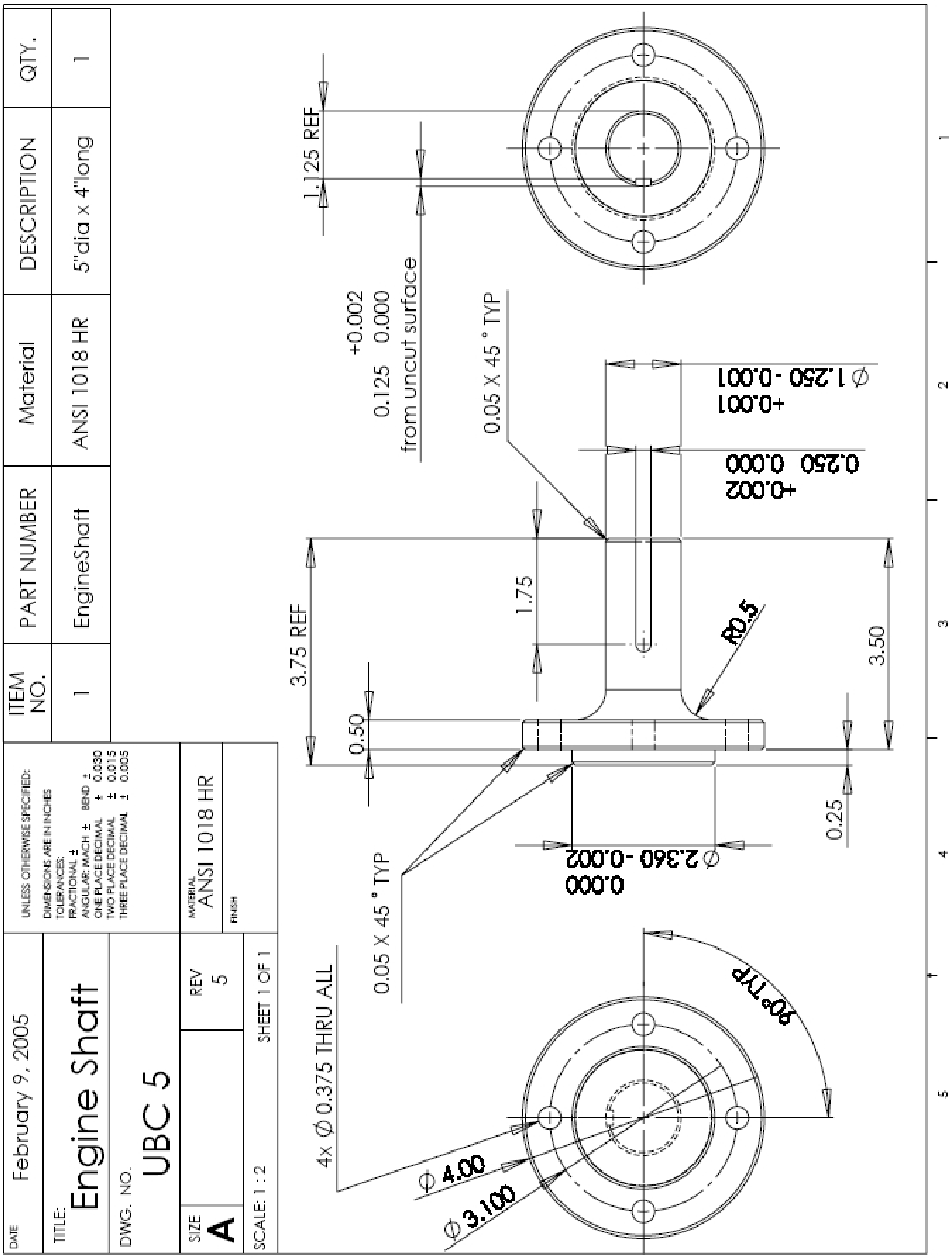


Appendix B - Engine Dimensions

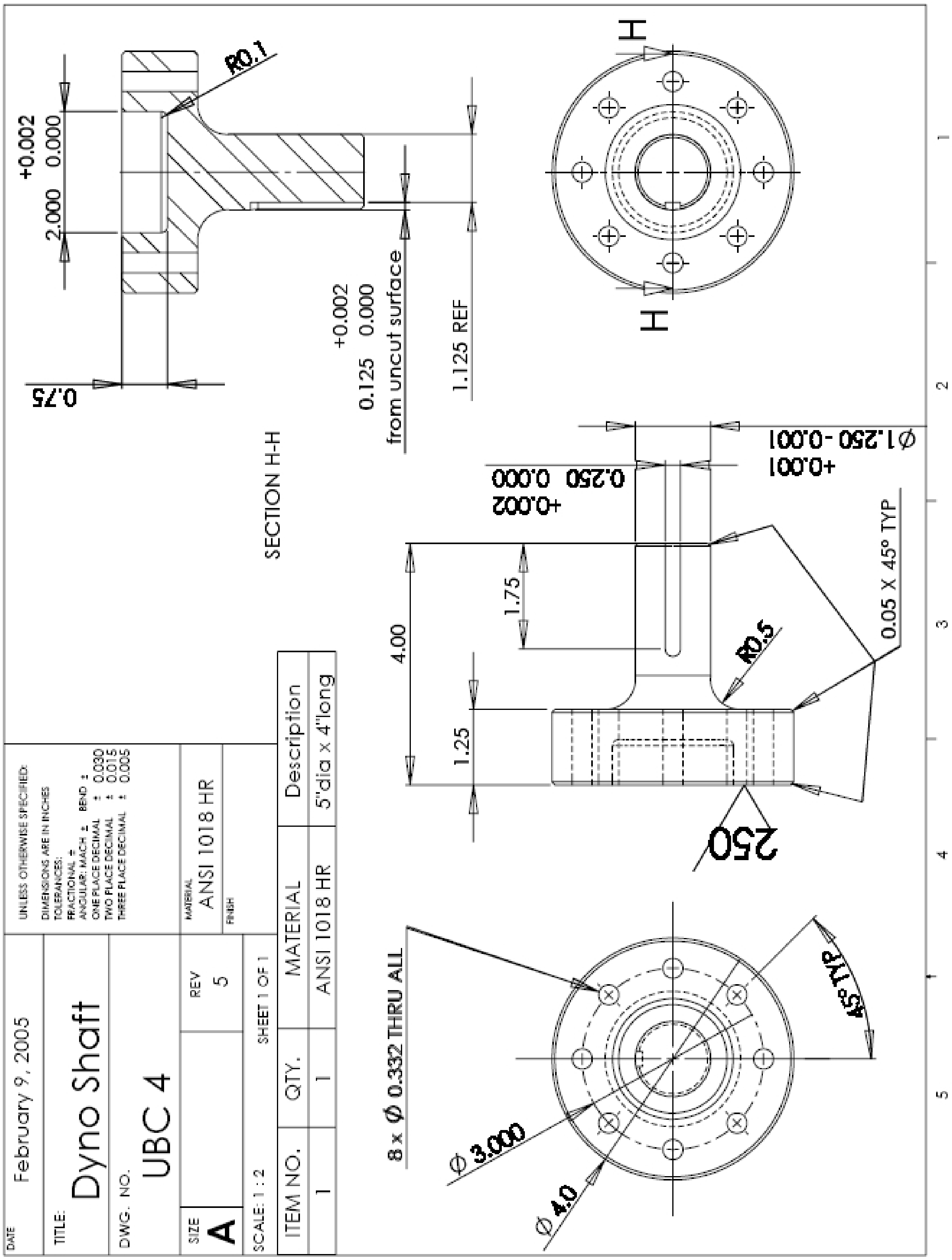


A	A'	B	C	D	E	F	G	H	I	J
583.8(22.98)	652.8(25.70)	230.0(9.06)	ϕ350.0(ϕ13.78)	ϕ247.0(ϕ9.72)	56.0(2.20)	396.0(15.59)	194.0(7.64)	609.7(24.00)	234.5(9.23)	200.0(7.87)

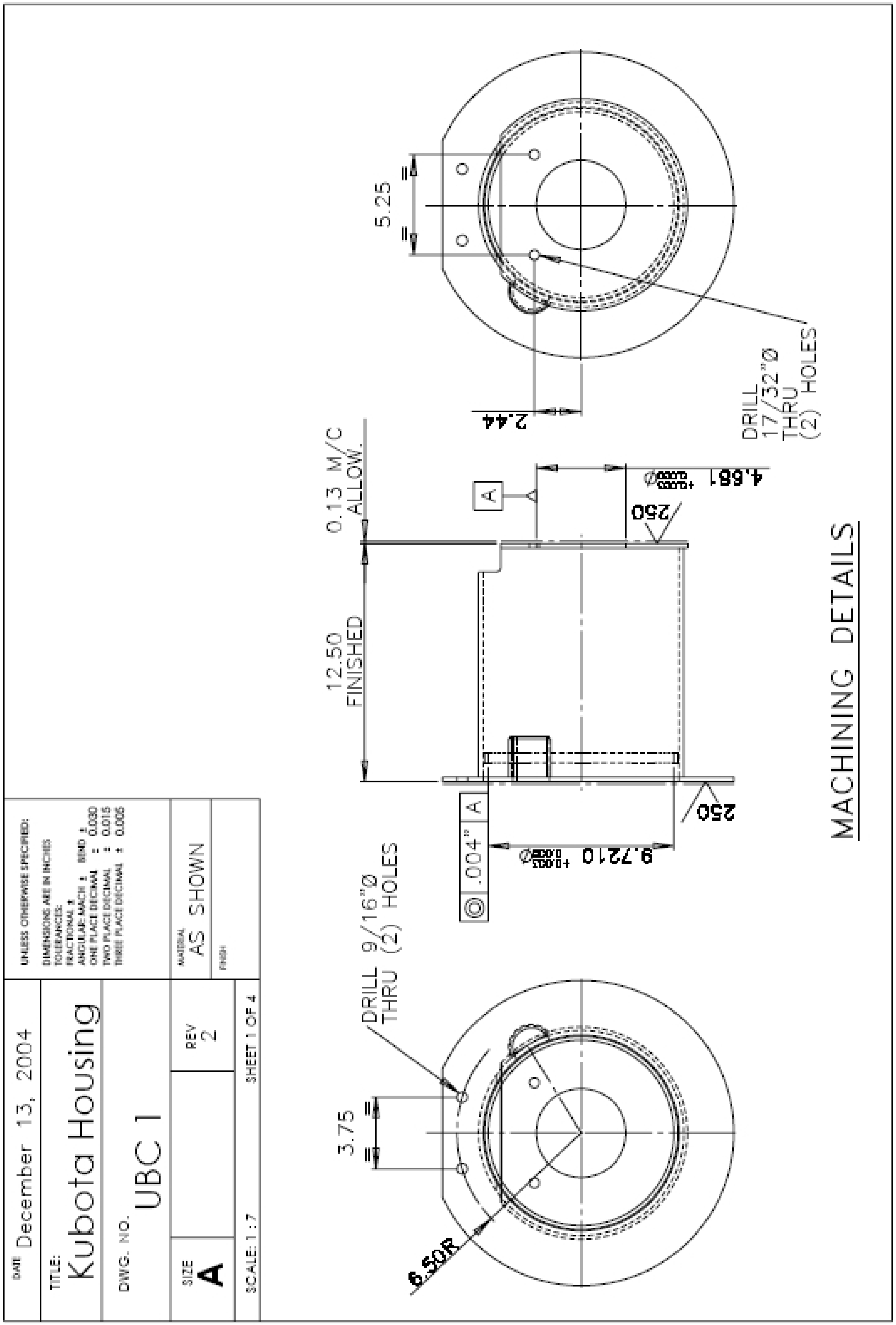
Appendix C - Engine Shaft Drawing



Appendix D - Dynamometer Shaft Drawing



Appendix E - Bell Housing Drawing



Appendix F - SAE Technical Paper 2004-01-0098

Effect of Various Lubricating Oils on Piston Deposits in Biodiesel Fueled Engines

Thomas R. Sem
Thermo-King Corporation, Division of Ingersoll Rand

ABSTRACT

Some customers of Transport Refrigeration Units (TRU's) powered by 2.1 liter diesel engines in Europe are requesting to run 100% biodiesel fuel in their TRU's.

The purpose of this paper was to find a way for users of 100% biodiesel fuel to maintain reliable diesel engine operation through selection of a better engine lubricant. Diesel engines that have been run with 100% biodiesel fuel have been found to have deposits inside the engine that are not found when running on fossil petroleum diesel fuel. This paper examines the effect of various engine-lubricating oils on engines running with 100% biodiesel fuel. The comparison of various engine oils was accomplished by evaluating the piston skirt and ring groove deposits when running 4 different engine oils for 1000 hours each on identical engines that are fueled by Soybean Biodiesel fuel.

Appendix G - SAE Technical Paper 2004-01-1039

Behavior of a Diesel Injection System with Biodiesel Fuel

James P. Szybist and André L. Boehman
The Pennsylvania State University

ABSTRACT

Biodiesel fuels are widely known to yield an increase in NOx emissions in many diesel engines. It has been suggested that the increase in NOx is due to injection timing differences caused by the low compressibility of biodiesel. In this work, comparisons of injection timing and duration were performed for diesel fuel and a range of biodiesel blends (B20 to B100). The fuel injector on a 4-stroke, single-cylinder, four horsepower, air-cooled, direct injection diesel engine was positioned in a spray chamber while the engine was motored and fuel was delivered to the injector by the fuel pump on the engine. Spray visualization and quantification of injection timing were performed in the spray chamber using an engine videoscope, light attenuation from a HeNe laser and fuel line pressure, and were synchronized to crank shaft position. Shifts in injection timing were observed between the fuel blends, amounting to a 1 crank angle (CA) degree difference between diesel fuel and pure biodiesel (B100). Combustion studies were also performed to see how the shift in injection timing affected the timing of the combustion process. There was an advance in ignition of up to 4 CA degrees with B100 which can be attributed, at least in part, to the advanced injection timing.

Appendix H - SAE Technical Paper 2003-01-1039

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Appendix I - Dynamometer Operation Instructions

Start-up Procedure

1. Turn both ventilation fans on high.
2. Check engine oil.
3. Visually inspect test stand and engine (oil/fuel leaks, disconnected wires, etc).
4. Check fuel level.
5. Ensure building exhaust condensate valves are closed.
6. Install dyno water tank partition plug.
7. Turn on dyno water supply valve ensuring cooling tower supply valve is closed.
8. Check sump operation

   Note: If sump is not working, close water supply valve

9. Open dyno brake primer valve half way
10. Open cooling tower filling valve until indicator level stabilizes. Once it stabilizes, close valve.
11. Check dyno water tank level.

    CAUTION: If the water level is below the top of the dyno brake inlet filter, do NOT start engine.

12. Close laboratory doors.
13. Power up dyno control console.
14. Check warning lights on console. If the prime or water lights are on, recheck steps 6 to 11.
15. Pull throttle full back.
16. Turn on ignition switch.
17. Start engine.

    Note: The glow plugs are not operational so the engine may take a few seconds to start.

18. Idle engine for 1 minute while checking: engine oil pressure warning light, dyno water level and dyno measurements (torque, power, airflow and RPM).
19. Increase RPM to 1200 by slowly pushing throttle forwards. Hold at 1200 RPM for 1 minute.
20. Repeat checks in step 18.
21. Increase RPM to 1800 and adjust load knob until RPM drops to 1700.
22. Once engine temperature reaches 150 F, increase RPM to 2800 with same load.
23. Once engine temperature reaches 170 F, testing can be started.

Shutdown Procedure

1. Idle engine for at least 3 minutes after any testing.
2. Turn off ignition and dyno console power.

   CAUTION: Exercise extreme care when entering laboratory. The engine will be very hot.

3. Enter laboratory and turn of dyno water supply.
4. Remove water tank partition plug.
5. Open cooling tower fill valve (it will drain through this one as well as fill).
6. Drain tank by manually activating sump pump float switch.
7. Drain condensate from building exhaust using the condensate drain valves.
8. Check engine for any leaks or obvious problems.
9. Turn off laboratory ventilation fans.

Appendix J - Fuel Flow Calculations

$m_{initial} := 9.117$ kg $\quad m_{final} := 3.194$ kg $\quad time := 1$ hour

$Q_{fuel} := \frac{m_{initial} - m_{final}}{time}$ $\quad Q_{fuel} = 5.923 \ \frac{kg}{hr}$ Mass flow rate of fuel

$Q_{fuel} := \frac{5.923}{.4536}$ $\quad Q_{fuel} = 13.058 \ \frac{lbm}{hr}$

$P_{average} := 22.5$ kW $\quad P_{average} := \frac{22500}{747}$ $\quad P_{average} = 30.12$ hp

$bsfc := \frac{Q_{fuel}}{P_{average}}$ $\quad bsfc = 0.434 \ \frac{lb}{hp \cdot hr}$

Fuel Heating Value and Fuel Conversion Efficiency

$HV_{diesel} := 19858 \ \frac{Btu}{lb}$ Heating value of regular diesel

$\eta_f := \frac{2545}{bsfc \cdot HV_{diesel}}$ $\quad \eta_f = 0.296$ Fuel Conversion efficiency - Mechanical energy out vs fuel energy energy in

Appendix K - Project Finances

Table 2 - Project Finances

Team Purchases

Item	*Purchaser*	*Purchased From*	*Price (Tax inc.)*
Chain and shackles	Leif	Home Depot	$ 11.90
Grinding/sanding supplies	Leif	Canadian Tire	$ 14.56
Misc. fasteners	Leif	Lordco	$ 9.44
Misc exhaust pieces	Leif	Canadian Tire	$ 19.38
Misc exhaust pieces	Leif	Canadian Tire	$ 6.87
Oil filter	Leif	Qualicum Auto	$ 10.72
Oil Butt connectors Fuse link	Leif	Lordco	$ 23.46
Plumbing supplies	Leif	Hillcrest plumbing	$ 7.74
Plumbing and fasteners	Leif	Home Depot	$ 19.59
Engine temperature gauge	Leif	Canadian Tire	$ 14.35
Flexible Coupling	Darren	BC Bearing	$ 99.23
Fasteners	Darren	Home Depot	$ 2.06
Diesel Fuel	Darren	Shell	$ 15.00

TEAM PURCHASES $ 254.30

Project Funding Purchases

Item	*Purchaser*	*Purchased From*	*Cost*
Material for Shafts	Mech Eng Stores	Metal Supermarkets	$ 119.70

PROJECT FUNDING TOTAL $ 119.70

TOTAL PURCHASES $ 374.00

Donations

Item	*Purchaser*	*Contributor*	*Cost*
Bell housing material	N/A	Carmanah Design +	$ 124.40
Bell housing fabrication	N/A	Manufacturing Inc.	$ 552.90
Bell housing machining	N/A		$ 872.00
20 liters diesel	N/A	UBC Plant Ops	$ 20.00
10 liters B20	N/A		$ 10.00

TOTAL CONTRIBUTIONS $ 1,579.30

TOTAL PROJECT COST $ 1,953.30