BIODIESEL TEST ENGINE

SENIOR ENGINEERING DESIGN PROJECT
ARKANSAS TECH UNIVERSITY

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ABSTRACT

Biodiesel fuel, made from a variety of plant oils, is receiving growing interest as a possible substitute for petroleum derived diesel fuel. The bulk of research to date has been conducted on biodiesel fuel produced from fresh soybean or seed oil. Students in the Mechanical Engineering Department at Arkansas Tech University (ATU) are undertaking a study to evaluate biodiesel fuel produced from used cooking oil. Various blends of biodiesel and standard diesel, ranging from 20% to 100% biodiesel, will be tested in a 1989 Chevrolet Silverado 3500 truck. The 6.2 liter diesel engine in the truck has previously operated for approximately 85,000 miles on standard diesel fuel.

Operating characteristics of the truck on standard diesel will be measured prior to use of the biodiesel blends to establish a baseline for comparison. The same characteristics will then be measured while using a series of biodiesel/diesel blends of 20 and 100% biodiesel. Evaluation will include road tests, chassis dynamometer tests, and emissions tests using a standard four gas emissions analyzer.

INTRODUCTION

Much research has been done in the field of biodiesel. Most of the tests were conducted with seed oil or "virgin oil". Virgin oil is vegetable oil or some other type of oil that has not been used in any process such as cooking. Very little research has been done on the use of used cooking oil as a source to make biodiesel. The goal of this project was to test the engine performance difference of standard number two diesel fuel to that of biodiesel fuel made from used cooking oil by the Chemistry Department at ATU. Three different fuel mixtures were used: 100% number two diesel, 20% biodiesel, and 100% biodiesel. To test the engine it was placed under several different load conditions with each of these mixtures. The fuel efficiency, engine power, torque, and exhaust emissions were tested and recorded so that they could be compared. From this data, a recommendation can be made for the viability of used cooking oil biodiesel as an alternative for fossil fuel diesel.

OBJECTIVES

The purpose of the project was to compare the fuel efficiency, engine power and torque, and exhaust emissions of biodiesel to that of standard diesel. The biodiesel test engine project contains the following objectives:

- Choose and Acquire Test Engine
- Modify Fuel System
- Test Biodiesel Performance

Project Assumptions

The following assumptions were made in order to complete the project.

- No changes to the vehicle, that would have a negative affect on testing, were made at anytime in the duration of this project.
- Driving variables, such as time of day, temperature, and weather, were relatively the same for each corresponding road test.
- The fuel remaining in the fuel lines while measuring the excess fuel drained from the tank is negligible since that particular fuel line is very small and short.

Materials and Methods

Materials:

Four different methods of loading a diesel engine were considered: brake dynamometers, power generators, water pumps, and a vehicular chassis. Due to budget constraints and other factors, a 1989 Chevrolet Silverado 3500 truck equipped with a 6.2 liter diesel engine was chosen as the test bed and can be seen in Figure 1. In order to perform road testing, the vehicle was added to ATU's auto fleet and was licensed and insured. The drivers were also approved to drive a school owned vehicle.

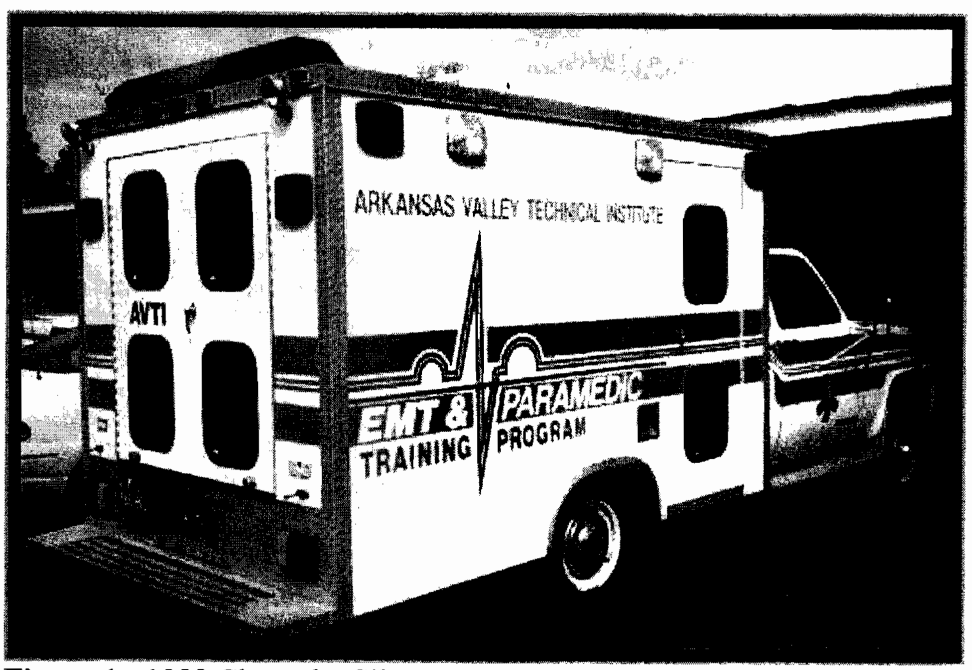

Figure 1: 1989 Chevrolet Silverado Ambulance

Because of the age of the vehicle, some components had to be replaced, which added to final cost of the project. These components included tires, windshield wipers, fuel tank switch, and a battery. Everything was purchased from project funds except for the tires, which were provided free of charge from ATU Ozark.

In order to obtain accurate fuel usage, a drain plug was placed in one of the two fuel tanks. This allowed the unused fuel left in that tank to be drained and measured, which was subtracted from the total amount supplied to that tank. Since the alcohol in biodiesel breaks down rubber, the rubber fuel lines were replaced with compatible lines. During the exhaust emissions testing, the fan clutch failed and was replaced in order to keep the engine from overheating and causing tainted emissions data. The costs of these modifications and repairs are contained in the Cost Analysis section of this report.

Fuel Efficiency:

Fuel efficiency tests were achieved by road testing the vehicle and obtaining the fuel mileage. Four different routes were selected in order to simulate different driving environments. The four routes are as follows: city, precipitous, highway, and freeway. These four routes were driven by two different drivers for each mixture of fuel and the fuel mileage was averaged together. This eliminates some of the error caused by different driving habits of each driver.

The equation for fuel mileage is distance traveled divided by the amount of fuel consumed. To accurately find the distance traveled on each route, a handheld Global Positioning System (GPS) unit was used to track each route. This unit was used in tandem with a portable laptop so that the route could be traced on an electronic map. This was done because the GPS unit sometimes loses signal and causes a "gap" in the trace. When there is a copy of this trace on an electronic map, the gaps can be manually filled in order to achieve maximum distance accuracy.

As mentioned earlier, fuel consumption was measured directly by subtracting the excess fuel remaining in the tank from the total fuel supplied to the tank. Using both of these values, the fuel mileage could be accurately measured.

Engine Power and Torque:

Engine power tests were carried out on a chassis dynamometer. The chassis dynamometer measures engine power transferred to the drive wheels. This is done by placing the drive wheels on the dynamometer rollers which put a resistance on the drive wheels. The vehicle's throttle is then fully opened and accelerates the rollers through to the maximum engine speed. The dynamometer then automatically calculates the engine power. Dynamometers also calculate the torque at the rear wheels, but in order to do this, a tachometer signal is needed. Unfortunately, the vehicle is not equipped with a tachometer and the torque could not be calculated within the dynamometer. However, the torque was found using a technique demonstrated later in the report. Each fuel mixture was tested six times with the dynamometer, which permitted an accurate average power for each mixture.

Exhaust Emissions:

Exhaust emissions tests were attained by using a five-gas exhaust analyzer. The five-gas analyzer gives the carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), hydrocarbons (HC), and oxides of nitrogen (NO_x) values as either a percentage or parts-per-million (ppm). A Snap-On MODIS exhaust gas analyzer was used for this analysis and the test values were recorded while the engine was operating at idle speed.

TEST RESULTS

Fuel Efficiency:

The routes that were chosen to perform the fuel efficiency tests were done so that each route had a fairly constant terrain. Highway 7 was chosen for the precipitous route. This is a fairly curvy road with steep grades, which put a significant load on the vehicle. Highway 22 was chosen because it is relatively flat and has a moderate speed limit of 55 miles per hour (mph). Interstate 40 was chosen for its high speed (70 mph speed limit) and relatively flat terrain. The city route crisscrosses across the city of Russellville, Arkansas. This route had many stop signs which created a great stop-and-go environment to represent a city driving environment.

The fuel efficiency test results are represented in Figure 2. However, there are a few discrepancies in these results that need to be addressed. When performing these tests, two different drivers drove each route for each fuel mixture. This was done to account for different driving habits and other uncontrollable environment variables, such as temperature, humidity, traffic, etc. The fuel mileages shown in Figure 2 are an average of both drivers for each route and fuel mixture.

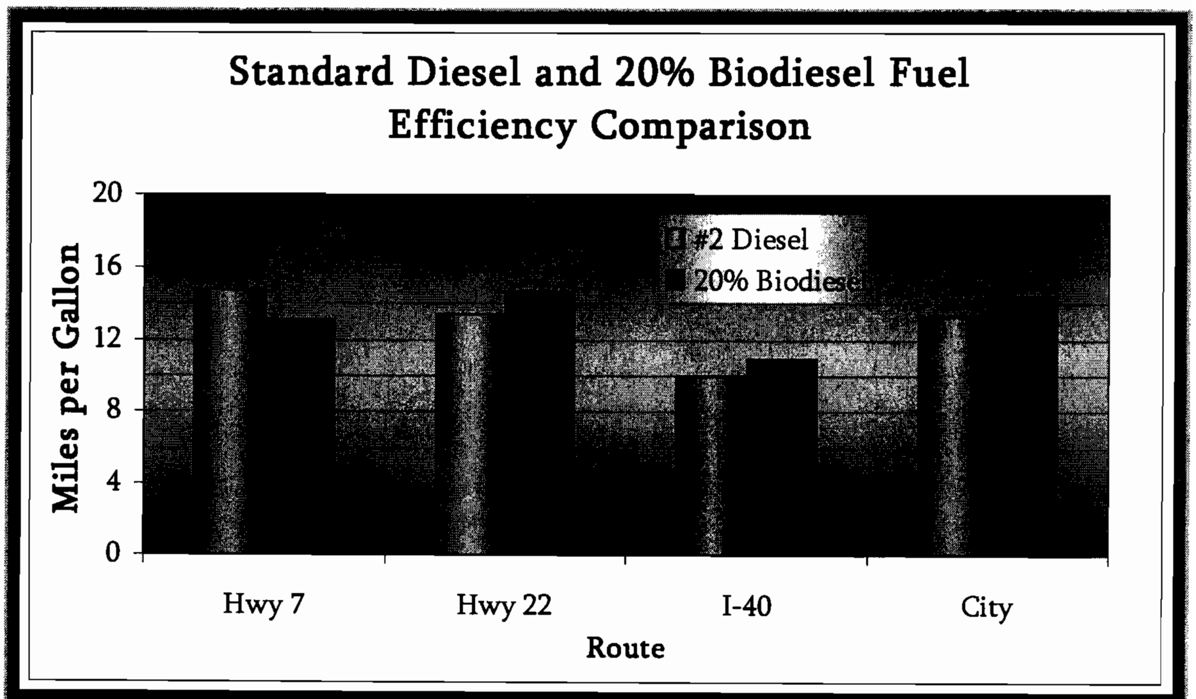

Figure 2: Standard Diesel and 20% Biodiesel Fuel Efficiency Comparison Chart

Also, there were some problems experienced with the 100% biodiesel mixture. Unfortunately, the biodiesel supply was abruptly interrupted due to shortages in used cooking oil. Because of this, the fuel efficiency tests were not completely finished. There was plenty of biodiesel for the 20% mixture tests, but there was roughly 20 gallons remaining for the 100% mixture tests. Each mixture test required approximately 70 gallons of fuel. The 20 gallons of fuel was enough to complete three of the eight 100% biodiesel runs: highway 22, highway 7, and the city route. However, these runs were concluded to be erroneous due to a couple of factors. First, the fuel filter became clogged on the second run and actually caused the engine to stop running. This was because biodiesel acts as a detergent and carries dirt and grime from the tank into the fuel lines, which eventually clogs up the fuel filter and halts the fuel flow. The fuel filter was quickly replaced to continue testing, yet some hesitation was still experienced during the remaining test. After examining the latest batch of biodiesel fuel, it was concluded that the fuel was contaminated before we received it. There were still food particles, along with other substances, that were not completely filtered out during the processing of the used cooking oil. Because of this, the 100% fuel mileage tests were not considered in the fuel efficiency test results.

Besides the previous discrepancies, these tests were successful in showing the differences in fuel efficiencies between standard diesel fuel and a 20% biodiesel mixture. It was surprising to find out that better fuel mileage was obtained with 20% biodiesel in three of the four routes. The percent increases for these three routes can be seen in Table 1. The percent decrease for the other route is shown as simply a negative increase.

Table 1: Fuel Mileage Values and Percent Increases

Route	#2 Diesel (mpg)	20% Biodiesel (mpg)	% Increase
Hwy 7	14.76	13.07	-11.4%
Hwy 22	13.38	14.61	9.2%
I-40	9.97	10.97	10.0%
City	13.34	14.43	8.2%

Engine Power and Torque:

The dynamometer tests were carried out on the vehicle using each fuel mixture. The dynamometer test is a very accurate measurement of engine power and torque, and is also very consistent between tests. The testing was performed at Dyno & Performance in Fort Smith, Arkansas. Their shop is equipped with a DynoJet model 224X chassis dynamometer. For each mixture, six tests were performed consecutively. As standard practice when running a chassis dynamometer, the first two tests are thrown away. They are usually not in line with the remaining tests due to factors such as engine operating temperatures and automatic calibrations within the dynamometer.

Raw test data was taken straight from the dynamometer computer and analyzed using Microsoft Excel. Unfortunately the dynamometer could not directly calculate the torque, but after using Equation 1, the engine speed in revolutions per minute (RPM) was found and used to calculate the engine torque. The formula used to calculate engine torque can be seen in Equation 2.

$$E = \frac{V \cdot G \cdot F \cdot 88}{C} \qquad \textbf{[1]}$$

where	E	is the engine speed (RPM)
	V	is the vehicle speed (mph)
	G	is the transmission gear ratio
	F	is the final drive gear ratio
	C	is the drive tire circumference (feet)
	88	is a conversion factor

$$T = \frac{33000 \cdot H}{2 \cdot \pi \cdot E} \qquad \textbf{[2]}$$

where	T	is the engine torque (foot-pounds)
	H	is the engine power (horsepower)
	E	is the engine speed (RPM)
	33000	is a conversion factor

After theses tests were completed, the engine performance could be compared with the different mixtures. The following charts represent the engine power and torque for each of the fuel mixtures. Figure 3 shows the average horsepower curves for the each of the fuel mixtures. This graph shows the horsepower at every engine speed interval. The maximum horsepower values are at around 3250 RPMS and begin to slowly drop off after that. At around these maximum values, the 100% diesel is approximately 2% higher than the biodiesel mixtures, which have almost identical values. It should be noted that the 20% and 100% biodiesel fuels are very similar throughout the entire curve. This means that there is a very minimal power difference between the two fuels.

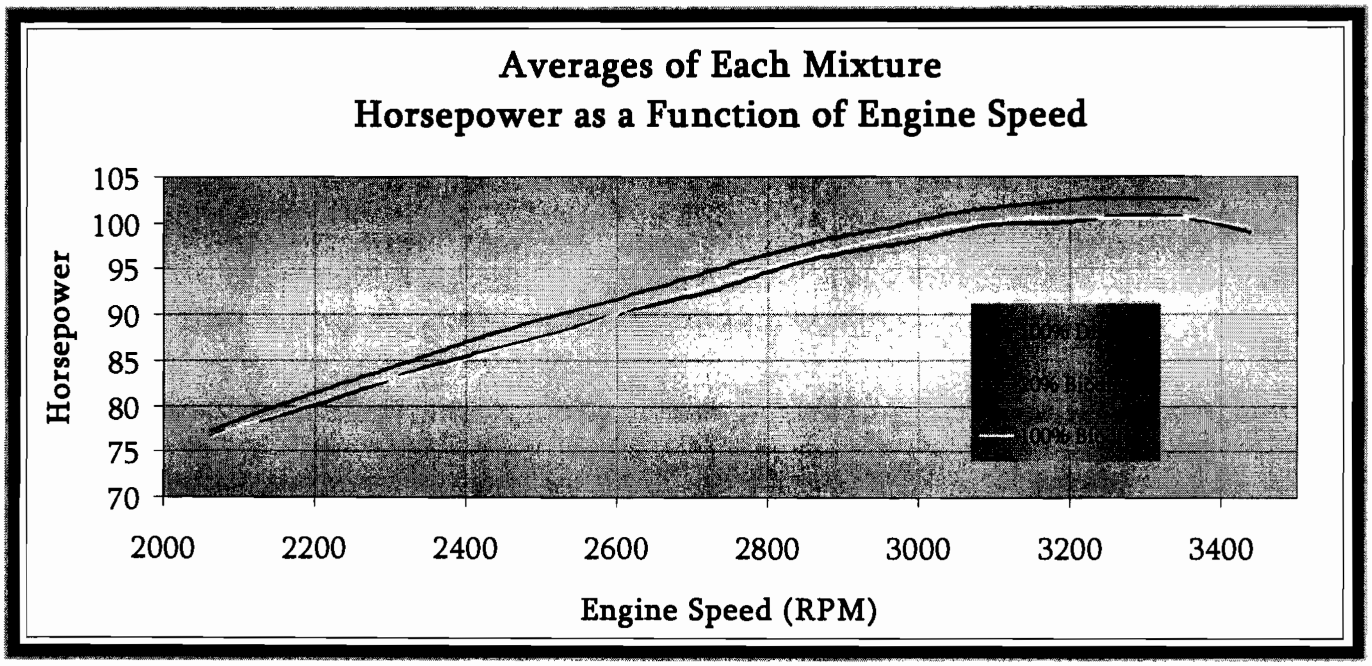

Figure 3: Average Horsepower as a Function of Engine Speed for All Three Mixtures

Figure 4 represents the torque curves for each of the fuel mixtures. The accuracy of these curves is questionable. Since diesel engines produce the majority of their torque at very low engine speeds, the dynamometer tests are not extremely accurate. This has nothing to do with the dynamometer, but in the way these particular tests were performed. Since the vehicle is not equipped with a kick-down cable for the transmission, the tests had to be run in second gear. Because of this, the engine did not start revving at the same point on every test-run. Therefore, the torque readings could be false since the throttle was fully opened at different RPM values. This caused the torque curves to be misleading and do not correlate well with the other tests performed in this project.

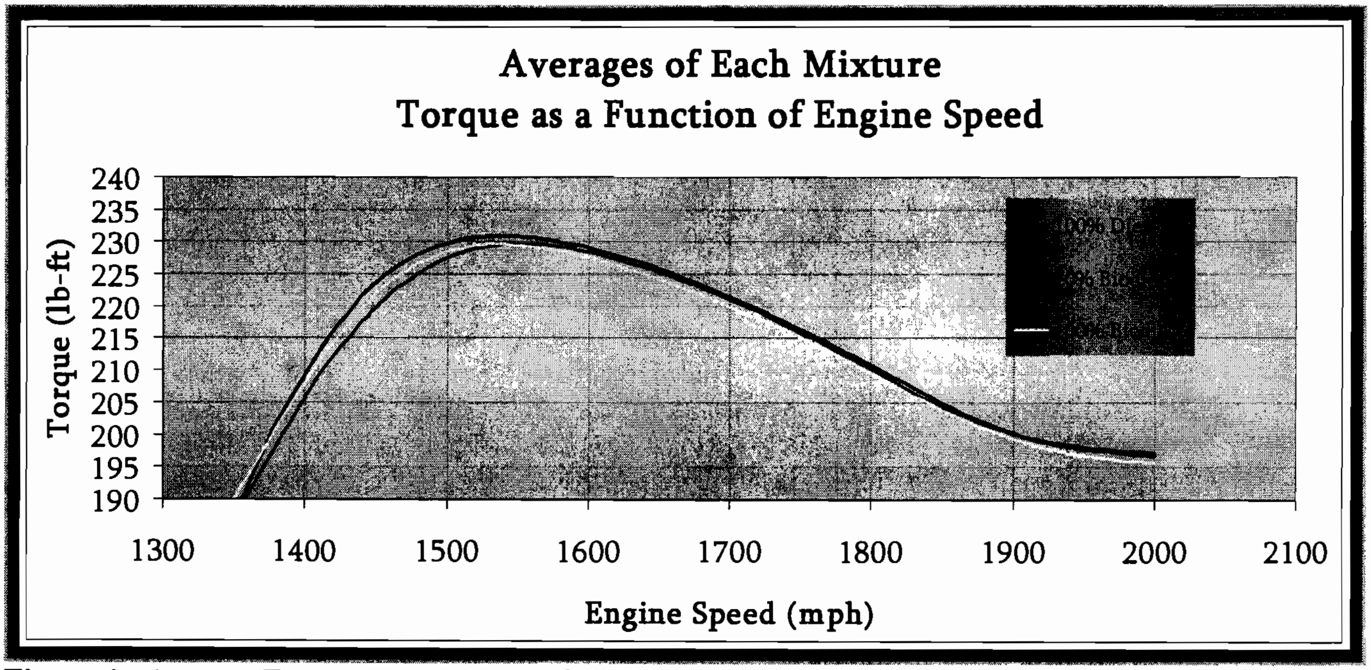

Figure 4: Average Torque as a Function of Engine Speed for All Three Mixtures

Exhaust Emissions:

After contemplating these emission values (Table 2) and comparing them to published values, it is uncertain how correct the measurements are. However, they are accurate for comparative purposes. As expected, the NO_x values rose approximately 1% when going from the #2 diesel to the 20% biodiesel and approximately 11% when going from the 20% biodiesel to the 100% biodiesel. NO_x emissions are a contributing factor in the formation of smog and this is one downside to biodiesel emissions. The O_2 values fluctuated, having no definite pattern when switching the fuel mixtures, but overall did rise when using biodiesel. However, O_2 emissions are not harmful to the environment so any rises in these emissions are welcome. CO emissions are harmful to the environment, and biodiesel did not cause any significant increase in these emissions. CO_2 did drop when using the biodiesel. A 2.5% drop in CO_2 was seen when changing from #2 diesel fuel to 20% biodiesel mix and then remained relatively unchanged when changing to the 100% biodiesel fuel. The HC levels went unaltered, yet should have decreased[i]. HC emissions are also a contributing factor in the formation of smog.

Table 2: Emissions Data

Emission Gas	#2 Diesel	20% Biodiesel	100% Biodiesel
NO_x, ppm	179	181	201
O_2, %	17.75	17.95	17.81
CO_2, %	2.06	2.01	2.00
CO, %	0.00	0.01	0.01
HC, ppm	0	0	1

COST ANALYSIS

The major cost of this project was standard #2 diesel fuel. It had to be purchased from local fuel stations at roughly $2.30 per gallon. Other large purchases were made in order to repair various components in the vehicle, as explained earlier in the report. The only labor that had to be paid for was the operation of the chassis dynamometer. They charged 100 dollars per hour and the process took one and a half hours. Thankfully, the remaining labor costs were not an issue since ATU Ozark installed the drain plug and tires free of charge and the Russellville Area VoTech assisted in the installation of the fan clutch for free. The VoTech also assisted in performing the five-gas analyzer tests without charging a fee. All of the remaining costs are contained in Table 3 and it should be noted that all prices are extimates.

Table 3: Project Costs

Part	Quantity	Price	Purchase Location	Total Cost
Diesel Fuel	174 Gallons	$2.30/gallon	Exxon	$400.00
Fan Clutch	1	$66.00	O'Reilly's Auto Parts	$66.00
Drain Plug	1	$5.00	Warrens Auto Parts	$5.00
55 Gallon Barrel	1	$8.00	Hill Top Mall	$8.00
Fuel Filter	1	$21.00	O'Reilly's Auto Parts	$21.00
Fuel Tank Switch	1	$9.00	O'Reilly's Auto Parts	$9.00
Windshield Wipers	2	$5.00	Wal-Mart	$10.00
Battery	1	$75.00	Wal-Mart	$75.00
Fuel Pump	1	$40.00	Tractor Supply	$40.00
Fuel Containers	2	$5.00	Tractor Supply	$10.00
Ambulance	1	$0.00	ATU	$0.00
Tires	4	$0.00	ATU Ozark	$0.00
Dynamometer Labor	1.5 hours	$100/hour	Dyno & Performance	$150.00
Tire & Drain Install	8 hours	$0/hour	ATU Ozark	$0.00
Gas Analyzer Labor	5 hours	$0/hour	Russellville VoTech	$0.00
Fan Clutch Install	1 hour	$0/hour	Russellville VoTech	$0.00
			Total:	$794.00

MANAGEMENT PLAN

To complete the project on time, a schedule was followed closely. The months of January and February consisted of researching the use of biodiesel. The purchasing and acquisition took place during February and March. Purchasing was originally estimated to only take a couple of days, but ended up taking over a month. This was due to the time needed to register the vehicle. Testing of the biodiesel lasted 34 days during the months of March, April, and May. All of this information was compiled into a Gantt chart shown in Figure 5.

Task Name	Duration	Start	Finish
Research	35 days	Mon 1/3/05	Fri 2/18/05
Purchasing and Developme	24 days	Wed 2/9/05	Mon 3/14/05
Testing	34 days	Tue 3/15/05	Sun 5/1/05
Writing Report	19 days?	Tue 4/12/05	Fri 5/6/05

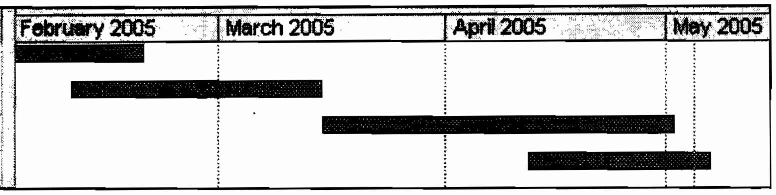

Figure 5: Project Schedule

SAFETY AND ENVIRONMENTAL EFFECTS:

A few safety issues were addressed while working on this project. Diesel and biodiesel fuels are an eye and skin irritant and eye protection and gloves were worn every time the fuel was being handled. Loose fitting garments were prohibited while working near the engine bay of the vehicle in order to prevent clothing from being caught up in the high speed engine components. Other basic safety practices were followed, such as closed toe shoes, working in well-ventilated areas, and obeying all traffic laws while driving the vehicle.

Diesel engines produce byproducts that are harmful to the environment. Carbon dioxide is primarily the most harmful byproduct. Other harmful byproducts include sulfur dioxide, carbon monoxide, hydrocarbons, and benzene. Particulate matter, also known as soot, is also very common when dealing with diesel engines running on standard diesel fuel. However, when running Biodiesel fuels, these harmful byproducts are greatly reduced, causing less harm to the environment. It should be noted that any harm to the environment caused by this project was less than or equivalent to the harm caused by most automotive diesel applications.[ii]

CONCLUSION

Overall, biodiesel is a viable alternative to diesel created from fossil fuels with regard to engine performance. Exhaust emissions were somewhat cleaner and are more environmentally friendly. Also, biodiesel exhaust fumes do not have a bad odor and is safer to breath. Engine power differences between the two fuels are very low, with a maximum power loss of around 2%. This power loss is so low that the driver would not be able to tell the difference in drivability.

A fuel mileage increase was experienced in three of the four cases and is somewhat surprising. This does not correlate well with the power losses experienced on the same fuel. Normally, less power from the same engine would decrease fuel efficiency. This fuel efficiency increase cannot be explained with the data found in this project. Therefore, it is determined that further investigation into this occurrence is needed to explain why there was a fuel efficiency increase while engine power decreased. Also, exhaust emissions testing should probably be performed with another exhaust gas analyzer in order to confirm these exhaust emissions levels, as most were on the low side of normal emissions values.

APPENDICES

These are included in the "Biodiesel.zip" file.

Appendix A:	Average.xls
Appendix B:	20%Biodiesel.xls
Appendix C:	100%Biodiesel.xls
Appendix D:	100%Diesel.xls
Appendix E:	Mixcomparison.xls
Appendix F:	20%Biodiesel.txt
Appendix G:	100%Diesel.txt

PERCENT CONTRIBUTIONS

Report Contributions:

Josh Ferguson:	80%
Matt Hamilton:	20%

Project Work Contributions:

Josh Ferguson:	50%
Matt Hamilton:	50%

REFERENCES

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[i] National Biodiesel Board. *Biodiesel Emissions.* Retrieved May 2, 2005, from http://www.biodiesel.org/pdf_files/fuelfactsheets/emissions.pdf

[ii] Global Stewards. *Biodiesel-The Alternate, Vegetable-Based Fuel for Diesel Engines.* Retrieved January 20, 2005 from http://www.globalstewards.org/biodiesel.htm