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# Biodiesel, Commercialization of a Renewable Fuel

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## **Executive** Summary

The commercialization of biodiesel will require acceptance by EPA, engine manufacturers, and fleet operators. Demonstrations that there are no durability problems and that the use of biodiesel has significant emissions benefits are primary factors in developing this acceptance.

NIPER's approach toward the commercialization of biodiesel was to first conduct screening tests to determine the optimum level of methyl soyate in diesel fuel and best adjustments to fuel and engine parameters. These tests were preparatory to a 1000-hour test for durability assessment and EPA emissions deterioration factor determination. Steady state tests were conducted with a current technology heavy duty diesel engine--a Cummins L10 with electronically controlled fuel injection. The biodiesel fuels were blends of methyl soyate in diesel fuel. The test fuels covered the range of 0 to 100 % methyl soyate. Engine performance was essentially the same for all levels of methyl soyate. The results of the emissions tests showed significantly lower levels of hydrocarbons (HC), carbon monoxide (CO) and particulates with biodiesel. The effect on emissions was nearly linear with the methyl soyate content of the fuel.

Aldehyde emissions levels were not affected by the methyl soyate. There was some concern about this because of the potential for the methyl ester being a precursor of formaldehyde.

There was only one emissions problem with biodiesel--a small increase in nitrogen oxides (NOx).

The conclusion drawn from the results of the first screening tests was that the optimum level of methyl soyate is approximately 20%. At this level, NOx emissions are within the range where achievement of emission goals should be possible by adjustment of fuel or engine parameters. Also, any adverse effects on low temperature flow would be minimal and, perhaps most important, the incremental increase in fuel cost is not excessive.

The next phase of work dealt with control of NOx emissions. Two approaches were examined--fuel treatment and engine parameter adjustment. The fuel treatment option allows direct substitution of biodiesel without need for engine adjustment. This allows the full emissions benefits of biodiesel and the interchangability of biodiesel and petrodiesel without need for engine adjustment. With engine adjustment there are probably some emissions/efficiency trade-offs.

The fuel was treated by adding a heavy alkylate. This is a low cetane, non-aromatic petroleum refinery stream. With the treated fuel all emissions were reduced to below baseline levels with no fuel consumption penalty.

The engine adjustment for NOx control was to retard the injection timing. This resulted in reduced NOx emissions (although not as low as baseline), but with penalties--increased particulates and increased fuel consumption.

The fuel treatment approach appears to be superior to engine adjustment but this conclusion is based on steady state tests. This needs to be confirmed in transient tests. The results of these transient tests will be used to select the fuel/engine conditions for the subsequent 1000-hour test for durability and emissions deterioration assessment.

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# Biodiesel, Commercialization of a Renewable Fuel

## Introduction

This project, jointly sponsored by the U.S. Department of Energy and the National SoyDiesel Development Board, is designed to develop information to aid in the acceptance of SoyDiesel as a commercial transportation fuel. Particular emphasis is placed on the performance of the fuel in a heavy duty diesel engine, the Cummins L-10. Emissions (via the 13-mode emissions test and similar tests) as a function of fuel blend ratio (SoyDiesel and standard low sulfur diesel) were determined. Additional blending studies and engine parameter adjustments were done to optimize the performance of the fuel. The emissions studies included particulates and aldehydes which are not a standard part of the 13-mode test. Results of the Cummins L-10 tests are discussed in Section I of this report.

Emissions tests of diesel powered pickup trucks were run on a chassis dynamometer by the Federal Test Procedure (FTP). These tests also determined emissions as a function of SoyDiesel/standard low sulfur diesel blend ratio. Results of these tests are discussed in Section II.

The effects of retarded injection timing with the Cummins L-10 will also be determined in transient duty testing.

Intermediate term plans are to conduct a 1000-hour accumulation test for durability assessment and determination of emissions deterioration factors.

## Section I.

### Effects of Biodiesel Fuels on Exhaust Emissions of a Cummins L10 Engine

The overall objective of this work was to determine the effect of methyl soyate-diesel fuel blends on the exhaust emissions from a Cummins L10-280E diesel engine. The specific objective was to determine the optimum fuel blend with respect to engine performance.

### Test Methodology and Test Parameters

Engine

Cummins 6 cylinder, 10L direct injection diesel , turbocharged and aftercooled; ratings: 280 hp @ 2000 rpm, 900 lb-ft @ 1600 rpm

Emissions test procedures

Follow the protocol specified by the SAE for heavy-duty diesel engines (SAE J1003 steady-state engine dynamometer test)

Emissions measurements

Hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), carbon dioxide (CO2), particulates, aldehydes and ketones

Fuels

- Blending Stocks
  - Methyl Soyate (MeSoy)-Interchem
  - 0.05% Sulfur Diesel (LSDF)--Phillips Petroleum Co.
  - 0.4% Sulfur Diesel Test Fuel (MSDF)--Howell Hydrocarbons
  - Inspection data for the three fuel stocks are given in table 1.
- Twelve Test Fuels
  - 15, 20, 25, 55, 60, 65, 90, and 100 vol% MeSoy in LSDF
  - Neat LSDF
  - Neat MSDF
  - 20 vol% MeSoy + 10 vol% Ethanol in LSDF
  - 20 vol% MeSoy + 20 vol% Heavy Alkylate in LSDF
- Replicate tests
  - 3 with 100% MeSoy
  - 2 with 20% MeSoy/80% LSDF
  - 4 with 100% LSDF
  - 3 with 100% MSDF (data derived from a different project)

Results

A complete test with each fuel consisted of 16 engine operating modes. Composites for a simulated heavy duty transient cycle, the 13-mode cycle, and the ECE 24 cycle were obtained by applying suitable weighting factors to each mode. A comparison of the EPA certification results with the NIPER composites are given below.

| | **bsHC** | **bsCO** | **bsNOx** | **bsPart** |
|---|---|---|---|---|
| EPA cert | 0.3 | 2.9 | 4.3 | 0.23 |
| 1993 std | 1.3 | 15.5 | 5.0 | 0.25 (0.10 for buses) |
| 1994 std | 1.3 | 15.5 | 5.0 | 0.10 |
| NIPER | | | | |
| HD* 0.4%S | 0.29 | 1.4 | 6.9 | 0.14 |
| HD 0.05%S | 0.24 | 1.7 | 6.4 | 0.07 |
| 13 Mode 0.05%S | 0.29 | 2.9 | 7.1 | 0.09 |
| ECE 24 0.05%S | 0.20 | 4.1 | 6.6 | 0.09 |

*HD=simulated heavy duty transient cycle

The NIPER heavy duty simulation data for the 0.4% sulfur diesel fuel are in reasonable agreement with the certification results with the same type of fuel. This lends some credence to the use of steady-state tests for screening purposes.

Initial examination of the results of the first 13 tests showed extreme variability between replicate tests of the blended fuels. Tests with the neat fuels showed very good repeatability. Analyses of the retained fuel samples showed that the actual levels of methyl soyate in the blends were markedly different than the target values. This was probably caused by incomplete mixing in the initial fuel preparation. The blending sequence was :

1. Add components to a 55-gallon drum--50 gallons total fill
2. Mix by rolling drum
3. Pump 25 gallons into a second drum
4. Use second drum of fuel for first test
5. Use original drum for replicate test

The actual methyl soyate content was determined from measurements of specific gravity and sulfur content of the blending components (methyl soyate and low sulfur diesel fuel) and of the retained samples from the tests. The agreement between specific gravity and sulfur content was very good.

The fuel blending and mixing procedures for the subsequent tests were much more rigorous to ensure complete mixing. Laboratory experiments were conducted to determine if fuel separation or stratification would occur. The results indicated that there was no separation of the two materials after they had been well mixed.

Emissions trends were very similar to those reported for other heavy duty diesel engines. That is, emission levels of HC, CO, and particulate decreased significantly for the SoyDiesel blends compared to the neat diesel fuel. The decrease from the base fuel for these three components was about 5% per 10% incremental addition of methyl soyate to the fuel. NOx emissions tended to increase linearly with the level of methyl soyate in the fuel-approximately 1.4% per 10% incremental addition of methyl soyate. Fuel consumption increased about the same as NOx emissions, approximately 1.4% per 10% incremental addition of methyl soyate. These results are summarized in table 2 and are depicted graphically in figures 1-5.

Subsequent testing and evaluations of methyl soyate blends were directed at 20% blends. This level was selected on the basis of economics, fuel economy, and emissions. The effect on fuel economy is minimal-approximately 2% decrease in volumetric fuel economy. Control of NOx could probably be achieved with a small change in injection timing. If injection timing is significantly retarded, particulate emissions can increase markedly and fuel efficiency decreases.

It was hypothesized that the increase in NOx associated with methyl soyate fuels is related to cetane number or ignition delay characteristics. Fuels with very high cetane number (for example, normal decane) have been found to cause high NOx emissions, presumably due to very short ignition delay and high peak combustion temperature. There is much information in the technical literature that associates increased NOx emissions with lower cetane fuels. However, addition of aromatics causes the lower cetane value. Aromatics inherently have higher flame temperatures than saturates and, therefore, tend to cause higher NOx emissions. Two lower cetane blends of 20% methyl soyate were formulated. The non-aromatic low cetane components were ethanol (@10 vol%) and a heavy alkylate (@ 20 vol%). A single test was conducted with each of these fuels.

Emissions with both fuels compared favorably to the base fuel and to the (untreated) 20% methyl soyate blend. The only adverse consequence was an increase in HC emissions for the ethanol-containing fuel. This was perhaps caused by the high volatility of the alcohol compared to the distillate boiling range fuels. The high volatility and low flash point of ethanol would most likely preclude its acceptance in diesel fuel. Ethanol was used in this work because it was readily available for immediate testing. The heavy alkylate component should become more widely available in the future because of the limitations on the amount of high boiling materials in reformulated gasoline. There are other benefits that could be realized by addition of the heavy alkylate to the methyl soyate. Fuel flow properties are expected to be improved significantly. These include viscosity, pour point, and cold filter plugging. The lower lubricity of the alkylate should be more than offset by the superior lubricity of the biodiesel.

Another approach to reduce NOx emissions was to retard the injection timing (beginning of injection, BOI). An electronic control module that incorporated a 3” retarded BOI was acquired from Cummins. Tests with this module installed were conducted with the base fuel (low sulfur diesel), a 20% methyl soyate blend, and the methyl soyate/alkylate blend. For purposes of comparison, tests were also conducted at standard injection timing with the base fuel and the methyl soyate/alkylate blend. This was necessary because the climate control system in the engine test facility was unable to maintain ambient temperature and humidity at the levels of the earlier work. Results of these tests are given in table 3.

Results of operation with the retarded injection timing were not consistent for the three fuels tested. Retarding the injection timing resulted in reduced NOx emission rates for the base fuel and for the 20% methyl soyate blend. The changes were much smaller than expected, however, on the order of a 2-3% reduction in NOx emissions. The NOx emission rate for the 20% methyl soyate/retarded injection timing combination was still greater than the baseline. Also, particulate emissions were greater than the baseline.

The effects of retarded injection timing were significant only at low to mid range engine speeds. At higher engine speeds NOx emissions were not reduced when the timing was retarded. In fact, the tests with the soyate/alkylate blend showed an increase in NOx emissions with the retarded injection timing.

The fuel treatment option appears to be markedly superior to the retarded injection timing approach to NOx control. Moreover, it enables direct substitution of biodiesel for standard diesel fuel without the need to make engine/fuel system changes, This conclusion is based on results of steady state tests, however. The comparability of steady state results with transient test results has not yet been demonstrated. Therefore, in the upcoming transient emissions tests, both fuel treatment and retarded injection timing will be investigated. The results of these tests will serve as the basis for selection of the conditions for durability testing (i.e., 1000-hour test).

## Table 1. - Fuel Inspection Analysis

| Fuel No. | 9304 | 9301 | 9303 |
|---|---|---|---|
| Description | 0.05%S DF | 0.4%S DF | MeSoy |
| Specific Gravity | 0.850 | 0.853 | 0.884 |
| % Sulfur | 0.04 | 0.40 | 0.01 |
| Viscosity, cs @40°C | 2.6 | 2.9 | 4.1 |
| Distillation, °F | | | |
| IBP | 343 | 427 | |
| 10% | 439 | 467 | |
| 50% | 512 | 517 | |
| 90% | 601 | 606 | |
| EP | 651 | 669 | |
| HC Type, vol% | | | |
| Aromatics | 33 | 30 | |
| Olefins | 1 | 1 | |
| Saturates | 66 | 69 | |
| Cetane Number | 44.5 | 52.4 | 46.2 |
| Acid Value, mg KOH/g sample | | | 0.04" |
| Soap, wt% | | | 0.02’ |
| Completeness, % of fatty chains as methyl ester | | | 98.62* |
| Moisture, wt% by KF | | | 0.03” |
| Free Glycerine, wt% | | | 0.13* |

* Analysis by Procter & Gamble

Table 2. - Summary of Results of BioDiesel Tests with Cummins L10 Engine

Heavy-Duty Transient Simulation

| FUEL | Fuel lb/hphr | HC g/hphr | CO g/hphr | NOx g/hphr | Part g/hphr |
|---|---|---|---|---|---|
| 0.4% S DF | 0.353 | 0.267 | 1.44 | 7.17 | 0.116 |
| | 0.357 | 0.310 | 1.44 | 7.03 | 0.184 |
| | 0.359 | 0.304 | 1.27 | 7.03 | 0.123 |
| 0.05%S DF | 0.355 | 0.231 | 1.41 | 6.34 | |
| | 0.355 | 0.226 | 2.00 | 6.43 | |
| | 0.353 | 0.277 | 1.77 | 6.28 | 0.061 |
| | 0.345 | 0.242 | 1.73 | 6.61 | 0.079 |
| 15% MeSoy | 0.361 | 0.220 | 1.25 | 6.47 | |
| 20% MeSoy | 0.357 | 0.208 | 1.35 | 6.81 | 0.049 |
| | 0.361 | 0.220 | 1.30 | 6.88 | 0.089 |
| 25% MeSoy | 0.364 | 0.206 | 1.47 | 6.55 | 0.046 |
| 55% MeSoy | 0.384 | 0.108 | 1.08 | 6.99 | |
| 60% MeSoy | 0.381 | 0.106 | 1.30 | 7.10 | |
| 65% MeSoy | 0.384 | 0.156 | 1.00 | 7.12 | 0.047 |
| 90% MeSoy | 0.395 | 0.085 | 1.04 | 7.06 | |
| 100% MeSoy | 0.400 | 0.079 | 1.11 | 7.12 | |
| | 0.403 | 0.075 | 1.14 | 7.58 | |
| | 0.401 | 0.147 | 0.80 | 7.46 | 0.040 |
| 20% MeSoy+ 10% EtOH | 0.373 | 0.278 | 1.24 | 6.02 | 0.036 |
| 20% MeSoy+ 20% Alkylate | 0.355 | 0.224 | 1.30 | 6.33 | 0.033 |

## Table 3. - Results of Emissions Tests with Fuel and Engine Parameter Adjustment
## 7 Mode Simulation of Heavy Duty Transient Test

| MeSoy vol% | Injection Timing | bsfc lb/hp-hr | bsHC g/hp-hr | bsCO g/hp-hr | bsNOx g/hp-hr | bsParticulate g/hp-hr |
|---|---|---|---|---|---|---|
| **0** | standard | 0.342 | 0.19 | 1.59 | 6.52 | 0.071 |
| **0** | -3” | 0.343 | 0.22 | 1.32 | 6.43 | 0.067 |
| **20** | -3° | 0.354 | 0.18 | 1.04 | 6.66 | 0.074 |
| **20 + alk** | standard | 0.348 | 0.19 | 1.21 | 6.38 | 0.067 |
| 20 + alk | -3° | 0.350 | 0.17 | 1.23 | 6.47 | 0.067 |
| | | % Change from Baseline | | | | |
| **0** | -3” | 0 | 16 | -17 | -1 | -6 |
| **20** | -3” | 4 | -5 | -35 | 2 | 4 |
| 20 + alk | standard | 2 | 0 | -24 | -2 | -6 |
| 20 + alk | -3° | 2 | -11 | -23 | -1 | -6 |

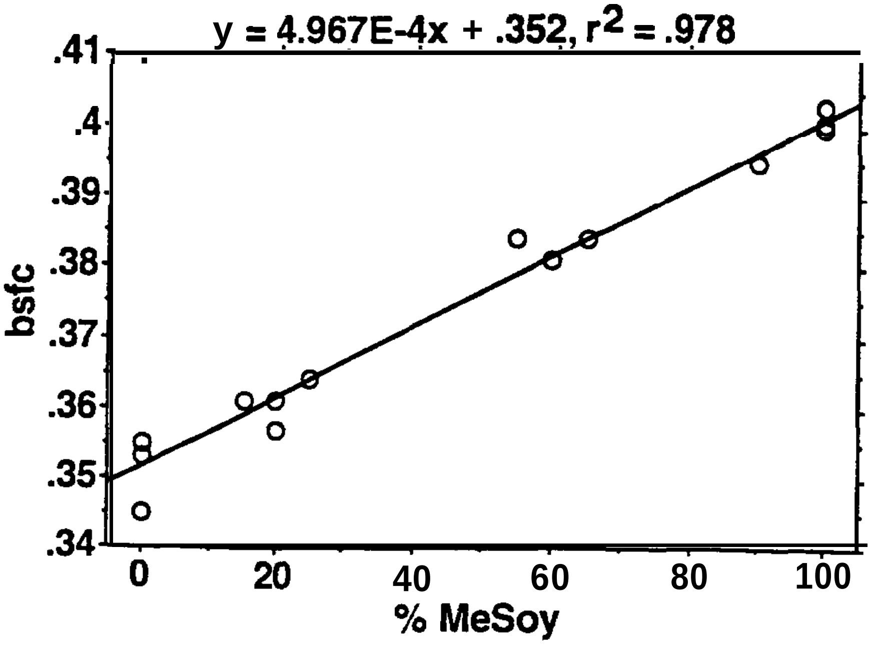

**Figure 1.** - Brake specific fuel consumption versus methyl soyate concentration - Cummins L10 engine.

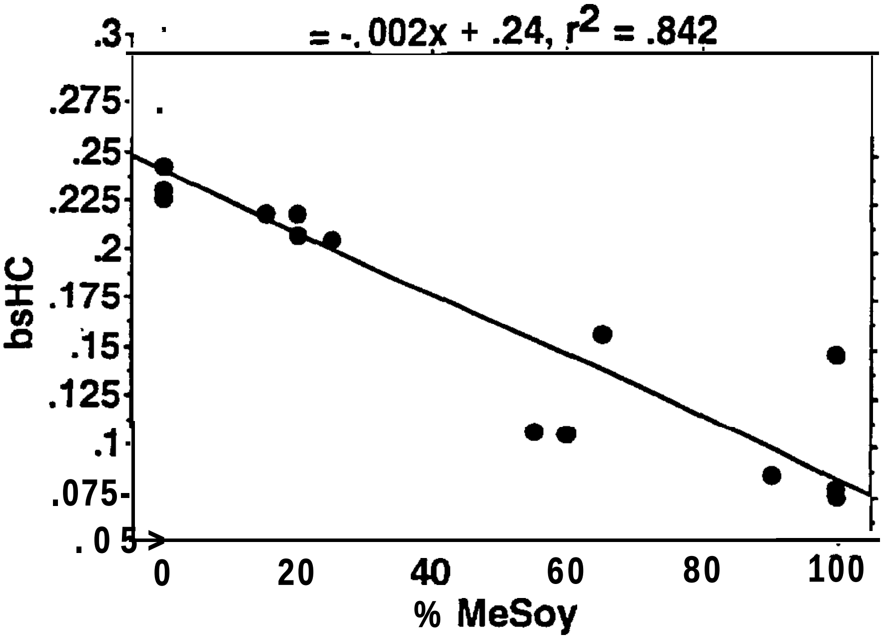

**Figure 2.** - Brake specific hydrocarbon emissions versus methyl soyate concentration - Cummins L10 engine.

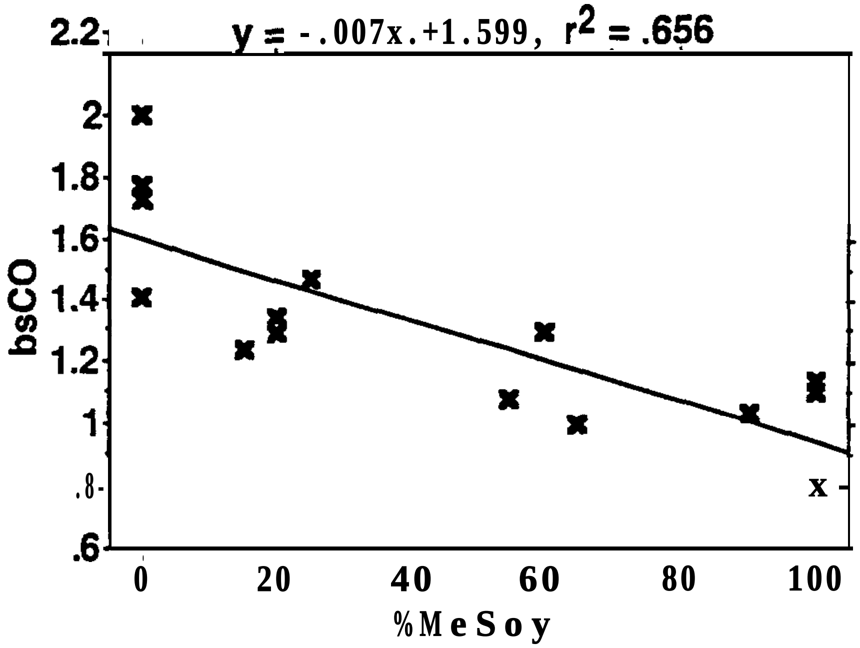

Figure 3. - Brake specific carbon monoxide emissions versus methyl soyate concentration - Cummins L10 engine.

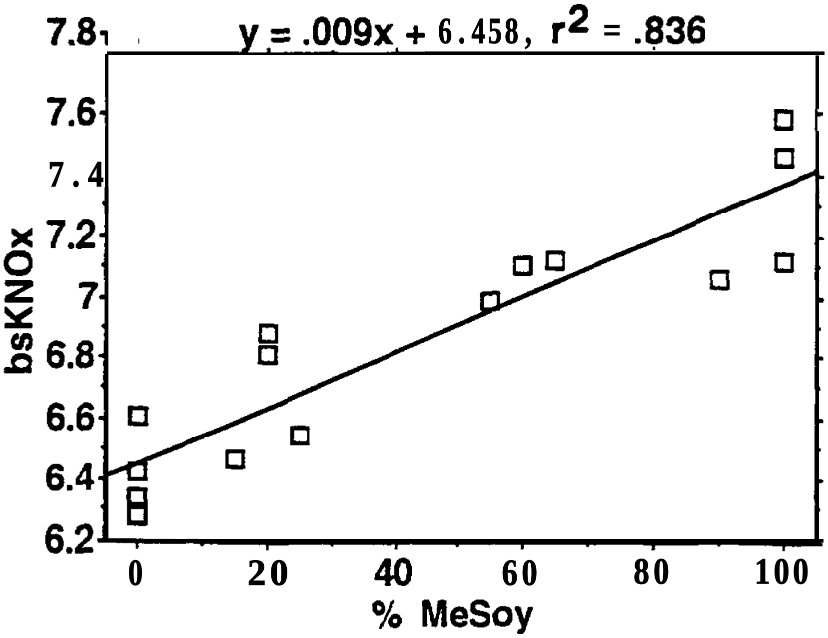

Figure 4. - Brake specific nitrogen oxide emissions versus methyl soyate concentration - Cummins L10 engine.

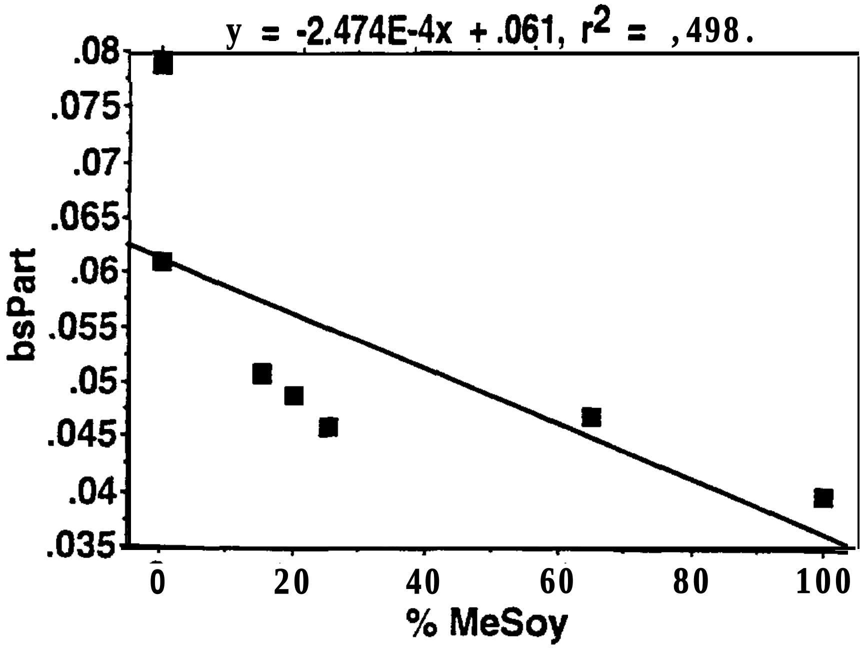

**Figure 5. - Brake specific particulates emissions versus methyl soyate concentration - Cummins L10 engine.**

## Section II.

## Effects of Biodiesel Fuels on Exhaust Emissions of Diesel Powered Pickup Trucks

The overall objective of this work was to determine the effect of methyl soyate-diesel fuel blends on the exhaust emissions from a pickup truck powered by a Cummins 5.9L diesel engine. The specific objective was to determine the optimum fuel blend with respect to engine performance. Additional testing was performed with two Cheyenne C2500 pickups powered by GM 6.2L diesel engines.

### Test Methodology and Test Parameters

Vehicles

**1992 model** year Dodge D-250 pickup with a 5-speed manual transmission
1991 model year Cheyenne C2500 pickups with automatic transmissions

Engines

Cummins 6-cylinder, 5.9L direct injection diesel, turbocharged and aftercooled; ratings: 160 hp @ 2500 rpm, 400 lb-ft @ 1700 rpm

GM &cylinder, 6.2L indirect injection, naturally aspirated

Emissions Test Procedures

Follow the protocol specified by the EPA for light-duty diesel vehicles (transient duty cycle chassis dynamometer test); 5500 lb vehicle test weight, 18.4 actual dynamometer horsepower @ 50 mph. All tests conducted from cold start @ 70°-75°F ambient temperature

Emissions measurements

HC, CO, C02, NOx, particulates, aldehydes and ketones

Fuels

Blending Stocks
    Methyl Soyate (MeSoy)-Interchem
    0.05% Sulfur Diesel (LSDF)--Phillips Petroleum Co.
    0.4% Sulfur Diesel Test Fuel (MSDF)--Howell Hydrocarbons
    Inspection data for the three fuel stocks are shown in table 1 of Section I
Eight Test Fuels
    0, 10, 20, 30, 50, 75, and 100 vol% MeSoy in LSDF
    Neat MSDF

Replicate tests
- 2 with 100% MeSoy
- 3 with 20% MeSoy/80% LSDF
- 2 with 100% LSDF

## Results

The emissions and fuel economy results for the Cummins 5.9L are summarized in table 4. Fuel economy results are reported as volumetric (mpg) and as diesel fuel energy equivalent (dfe). Data were computed for cold start (C ST), hot start (H ST), and FTP composite. The trends based on FTP composite results are not significantly different for either the cold or hot start phases.

Emission rates of NOx were quite high for a light duty truck- approximately 6 grams per mile (gpm). The EPA standard for vehicles of this weight class is 1.7 gpm. It should be noted that the EPA certification for this engine was as a heavy duty diesel engine. Also, no direct injection diesel-powered vehicle has ever been certified under the EPA light duty vehicle classification. Emission levels of HC, CO, and particulates were at or below the EPA standards for light duty vehicles.

Tests were conducted with two diesel fuels with different sulfur levels. Particulate emissions were significantly greater for the higher sulfur fuel, presumably due to increased level of sulfuric acid. NOx emissions were significantly lower with the higher sulfur (and higher cetane) fuel. Other workers have shown an inverse relationship between NOx emissions and cetane number (for petroleum-derived fuels).

The effect of the biodiesel fuels was unlike that reported for heavy duty transient tests of this or other diesel engines. There was no regular, systematic effect of soyate level on HC and NOx emissions. Particulate emissions increased as the content of methyl soyate in the fuel increased. With the 100% methyl soyate fuel, particulate emissions increased by more than 70% above the level with the low sulfur diesel. The CO and energy efficiency trends were in agreement with other work; that is, CO decreased and energy efficiency increased with increasing soyate level. The effects of soyate level are shown in figures 6-10.

Aldehyde emission rates were determined for soyate levels of 0, 10%, 20%, and 30%. There did not appear to be any fuel effect on aldehyde emissions. The levels were quite high for all three fuels-approximately 90 milligrams per mile. Typical levels are on the order of 3 to 10 mgpm for spark ignition-powered vehicles. No data are available for other light duty diesels because this measurement is not part of the certification procedure.

The vehicle exhibited good drivability with all fuels, indicating that there were no major malfunctions or misadjustments. Injection timing was not determined but the owner of the vehicle stated that it had not been changed from the original factory setting. The injection timing advance system was checked and was found to be operational.

Perhaps the cause of the differences in fuel response in these tests from other work is the duty cycle itself. The engine speeds and power demands differ significantly between the two tests. For example, the maximum power is about 50 hp (wheel horsepower) in the light duty test and 160 hp in the heavy duty test. Also, the maximum engine speeds are 2000 rpm (light duty) and about 2700 rpm (heavy duty). A closer examination of the severity of the transients might also show some pertinent differences.

In a project with a different sponsor, tests were performed on two diesel powered trucks to determine the effects of a biodiesel fuel on exhaust emissions. The trucks were identical-1991 model year Chevrolet Cheyenne C2500 powered by GM 6.2L diesel engines.

Exhaust emission tests were performed following the EPA light duty truck procedures. Duplicate tests were conducted with the tank fuel (25% methyl soyate, 75% 0.19% sulfur diesel) and single tests were conducted using a low sulfur diesel fuel and a blend of methyl soyate in the same low sulfur diesel fuel. A brief description of the fuels is given in table 5. A summary of the tests is shown in table 6.

Emissions levels were well within the EPA standards for light duty vehicles except for NOx. It should be noted that these engines were emissions certified under the heavy duty protocol (the same as the Cummins engine).

Test repeatability was quite good but there were significant differences in emissions between the two vehicles. Vehicle 2411 showed higher HC and particulate emissions and lower NOx emissions than vehicle 2413. This might be due to differences in injection timing and/or exhaust gas recirculation rate. No inspections were made to verify either possibility.

Results of the tests with the 0.05% sulfur diesel fuel showed that emission rates with the methyl soyate blend were about the same as the neat diesel fuel for unburned hydrocarbons and CO. With the soyate blend, on average, NOx increased by about 1% and particulates decreased by about 17%. The particulate reduction is in good agreement with results of heavy duty engine tests of other diesel engines. The increase in NOx is substantially less than that observed in heavy duty tests of other diesel engines.

## Table 4. - Summary of Tests of 1992 Dodge Pickup with a Cummins 5.9L Engine

| | Test | | | HC | HChe | CO | NOx | KNOx | co2 | Part | RCHO | FE | FE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | No. | Type | Fuel | gpm | gpm | gpm | gpm | gpm | gpm | gpm | mgpm | mpg | DF eq |
| 05/21/93 | 123 | FTP | 0% MeSoy | 0.01 | 0.01 | 3.30 | 6.20 | 6.15 | 549.4 | 0.273 | 89 | 16.2 | 16.2 |
| 06/03/93 | 133 | FTP | 0% MeSoy | 1.02 | 1.02 | 3.66 | 6.01 | 6.17 | 555.6 | 0.312 | | 16.0 | 16.0 |
| 05/14/93 | 120 | FTP | 10% MeSoy | 1.26 | 1.25 | 3.27 | 6.21 | 6.23 | 572.5 | 0.304 | 104 | 17.3 | 17.5 |
| 05/24/93 | 124 | FTP | 20% MeSoy | 0.66 | 0.86 | 3.12 | 6.13 | 6.00 | 560.1 | 0.270 | 79 | 17.7 | 18.1 |
| 06/02/93 | 128 | FTP | 20% MeSoy | 0.64 | 0.62 | 3.38 | 6.12 | 6.07 | 550.3 | 0.324 | | 17.7 | 16.1 |
| 06/07/93 | 136 | FTP | 20% MeSoy | | | 3.41 | 6.04 | 6.20 | 557.5 | 0.332 | | 17.7 | 18.1 |
| 05/20/93 | 122 | FTP | 30% MeSoy | 0.02 | 0.69 | 3.31 | 6.16 | 6.17 | 560.3 | 0.355 | | 17.5 | 18.1 |
| 05/13/93 | 117 | FTP | 60% MeSoy | 1.16 | 1.12 | 2.66 | 6.01 | 6.02 | 561.4 | 0.416 | 94 | 17.2 | 16.3 |
| 05/12/93 | 116 | FTP | 75% MeSoy | 1.41 | 1.20 | 2.70 | 6.04 | 6.02 | 562.6 | 0.364 | | 16.6 | 18.4 |
| 05/1 1103 | 114 | FTP | 100% MeSoy | 0.76 | 0.70 | 2.14 | 6.13 | 6.02 | 570.1 | 0.506 | | 16.1 | 16.2 |
| 05/25/93 | 125 | FTP | 100% MeSoy | 0.79 | 0.70 | 2.07 | 6.20 | 6.12 | 565.0 | 0.504 | | 16.4 | 16.6 |
| 05/27/93 | 126 | FTP | 0.4%S DF | 0.83 | 0.63 | 2.62 | 5.75 | 5.75 | 567.0 | 0.363 | | 17.0 | 17.9 |
| | | | | | | | | | | | | | |
| 05/21/93 | 123 | CST | 0% MeSoy | 0.06 | 0.08 | 3.01 | 6.65 | 6.64 | 581.8 | 0.204 | 62 | 17.2 | 17.2 |
| 06/03/93 | 133 | C ST | 0% MeSoy | 1.00 | 1.00 | 4.23 | 6.36 | 6.56 | 505.1 | 0.353 | | 16.8 | 16.6 |
| 05/14/93 | 120 | CST | 10% MeSoy | 1.30 | 1.36 | 3.86 | 6.62 | 6.65 | 600.6 | 0.346 | 100 | 16.6 | 16.7 |
| 05124103 | 124 | CST | 20% MeSoy | 0.05 | 0.03 | 3.65 | 6.60 | 6.44 | 564.0 | 0.205 | 70 | 16.0 | 17.3 |
| 06/02/93 | 126 | CST | 20% MeSoy | 0.03 | 0.01 | 3.80 | 6.51 | 6.43 | 580.5 | 0.405 | | 17.0 | 17.4 |
| 06/07/93 | 136 | CST | 20% MeSoy | | | 4.05 | 6.43 | 6.64 | 564.6 | 0.371 | | 16.9 | 17.3 |
| 05/20/93 | 122 | CST | 30% MeSoy | 1.02 | 0.08 | 3.66 | 6.50 | 6.58 | 585.2 | 0.361 | | 16.7 | 17.3 |
| 05113103 | 117 | C ST | 50% MeSoy | 1.27 | 1.20 | 3.05 | 6.51 | 6.36 | 566.4 | 0.415 | 63 | 16.5 | 17.5 |
| 05/12/93 | 116 | CST | 75% MeSoy | 1.41 | 1.30 | 3.10 | 6.51 | 6.43 | 589.3 | 0.462 | | 16.1 | 17.6 |
| 05/11/93 | 114 | CST | 100% MeSoy | 0.66 | 0.70 | 3.20 | 6.65 | 6.30 | 605.7 | 0.570 | | 15.4 | 17.4 |
| 05/25/93 | 125 | C ST | 100% MeSoy | 0.66 | 0.78 | 3.50 | 6.64 | 6.50 | 501.3 | 0.526 | | 15.7 | 17.8 |
| 05127103 | 126 | FTP | 0.4%S DF | 0.02 | 0.02 | 3.05 | 6.12 | 6.20 | 561.1 | 0.428 | | 17.2 | 17.2 |
| | | | | | | | | | | | | | |
| 05/21/93 | 123 | HST | 0% MeSoy | 0.67 | 0.67 | 3.01 | 5.67 | 5.65 | 534.0 | 0.264 | 05 | 18.7 | 18.7 |
| 06/03/93 | 133 | HST | 0% MeSoy | 0.06 | 0.96 | 3.23 | 5.73 | 5.66 | 537.6 | 0.281 | | 16.6 | 16.6 |
| 05/14/93 | 120 | H ST | 10% MeSoy | 1.16 | 1.15 | 2.63 | 5.00 | 5.01 | 561.5 | 0.272 | 100 | 18.0 | 18.2 |
| 05/24/93 | 124 | H ST | 20% MeSoy | 0.82 | 0.60 | 2.73 | 5.78 | 5.66 | 541 .o | 0.252 | 86 | 16.3 | 16.7 |
| 06/02/93 | 128 | HST | 20% MeSoy | 0.76 | 0.76 | 2.00 | 5.63 | 5.80 | 543.3 | 0.263 | | 18.2 | 18.6 |
| 06/07/93 | 136 | H ST | 20% MeSoy | 0.62 | 0.60 | 2.03 | 5.74 | 5.66 | 537.0 | 0.302 | | 18.4 | 18.0 |
| 05/20/93 | 122 | HST | 30% MeSoy | 0.85 | 0.62 | 2.86 | 5.66 | 6.65 | 541.4 | 0.335 | | 16.1 | 18.8 |
| 05/13/93 | 117 | HST | 50% MeSoy | 1.11 | 1.05 | 2.37 | 5.64 | 5.60 | 543.0 | 0.359 | 101 | 17.6 | 18.9 |
| 05/12/93 | 116 | HST | 75% MeSoy | 1.40 | 1.26 | 2.30 | 6.66 | 5.70 | 542.1 | 0.326 | | 17.5 | 19.1 |
| 05/1 1193 | 114 | HST | 100% MeSoy | 0.71 | 0.63 | 2.30 | 6.82 | 6.74 | 650.0 | 0.455 | | 16.7 | 16.8 |
| 05/25/93 | 125 | H ST | 100% MeSoy | 0.72 | 0.64 | 2.57 | 5.07 | 5.85 | 547.1 | 0.466 | | 17.0 | 19.2 |
| 05/27/93 | 126 | FTP | 0.4%S DF | 0.76 | 0.76 | 2.30 | 5.46 | 6.46 | 640.5 | 0.314 | | 18.5 | 18.5 |

**Table 5. - Description of Test Fuels for Cheyenne C2500 Pickups**
with **GM 6.2L Diesel Engines**

| Fuel | Tank<br>as received | Low s<br>Diesel | NIPER<br>Blend |
|---|---|---|---|
| **%S in** DF | 0.19 | 0.05 | 0.05 |
| %S in blend | 0.14 | 0.05 | 0.04 |
| % MeSoy | **25** | **0** | **25** |

## Table 6. - Summary of Emissions Test Results for Cheyenne C2500 Pickups, GM 6.2L Diesel Engines

| | | | | COMPOSITE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Date** | **Test No.** | **Fuel** | **Test Type** | **HC gpm** | **NMHC gpm** | **CO gpm** | **NOx gpm** | **Part gpm** | **FE mpg** | **ODOM** |
| Light duty Truck Emission Standards, g/mile | | | FTP | 0.80 | | 10.0 | 1.7 | 0.45 | | |
| Heavy Duty Diesel Emission Stdds, g/hp-hr | | | HD | 1.30 | | 15.5 | 5.0 | 0.25 | | |
| Vehicle<br>1991 | **#2411**<br>Chevrolet Cheyenne C2500/6.2 L Diesel | | | | | | | | | |
| 10/27/93 | 0202 | 25 vol%MeSoy/0.19%S DF | FTP | 0.24 | 0.24 | 1.05 | 3.41 | 0.16 | 15.9 | 18851 |
| 10/29/93 | 0207 | 25 vol%MeSoy/0.19%S DF | FTP | 0.32 | | 1.04 | 3.42 | 0.15 | 15.9 | 18862 |
| 11/01/93 | 0209 | 0.05%S DF | FTP | 0.34 | | 1.17 | 3.41 | 0.17 | 15.9 | 18880 |
| 11/02/93 | 0212 | 25 vol%MeSoy/0.05%S DF | FTP | 0.31 | | 1.16 | 3.41 | 0.15 | 15.4 | 18899 |
| Vehicle<br>1991 | **#2413**<br>Chevrolet Cheyenne C2500/6.2 L Diesel | | | | | | | | | |
| 10/27/93 | 0203 | 25 vol%MeSoy/0.19%S DF | FTP | 0.15 | 0.15 | 0.92 | 5.18 | 0.14 | 15.7 | 22073 |
| 10/28/93 | 0206 | 25 vol%MeSoy/0.19%S DF | FTP | 0.14 | | 0.98 | | 0.15 | | 22084 |
| 11/01/93 | 0208 | 0.05%S DF | FTP | 0.15 | | 1.00 | 5.04 | 0.13 | 15.8 | 22103 |
| 11/03/93 | 0214 | 25 vol%MeSoy/0.05%S DF | FTP | 0.17 | | 1.02 | 5.13 | 0.10 | 15.7 | 22123 |

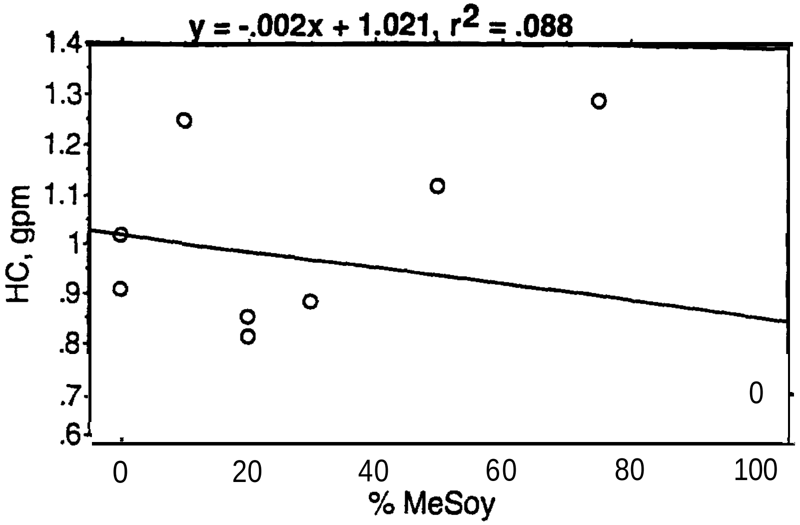

**Figure 6. - Hydrocarbon emissions versus methyl soyate concentration - Cummins 5.9L** engine.

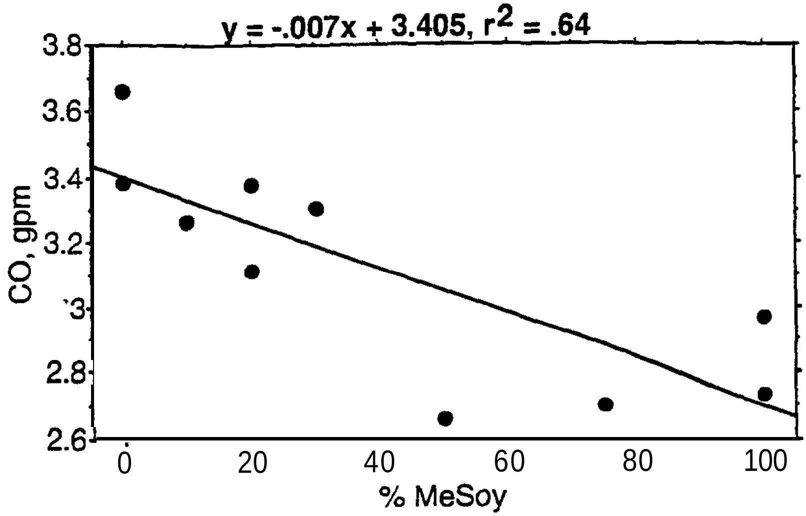

**Figure 7. - Carbon monoxide emissions versus methyl soyate concentration - Cummins 5.9L engine.**

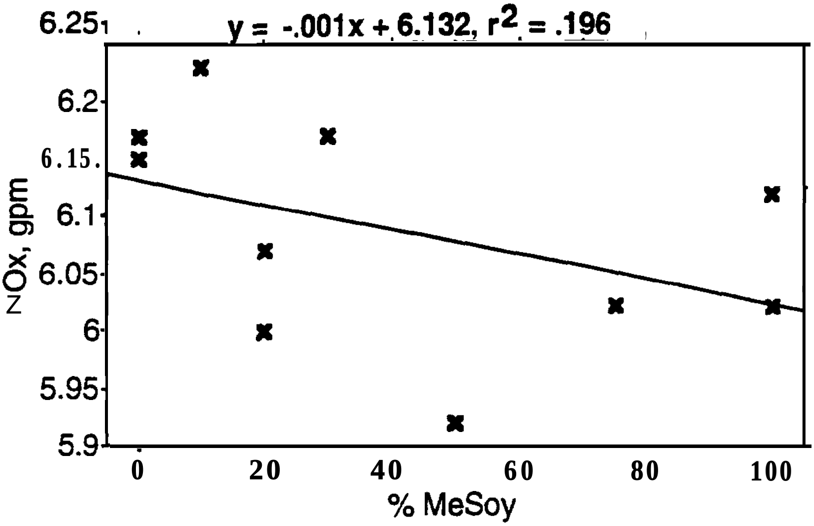

Figure 8. - Nitrogen oxide emissions versus methyl soyate concentration - Cummins 5.9L engine.

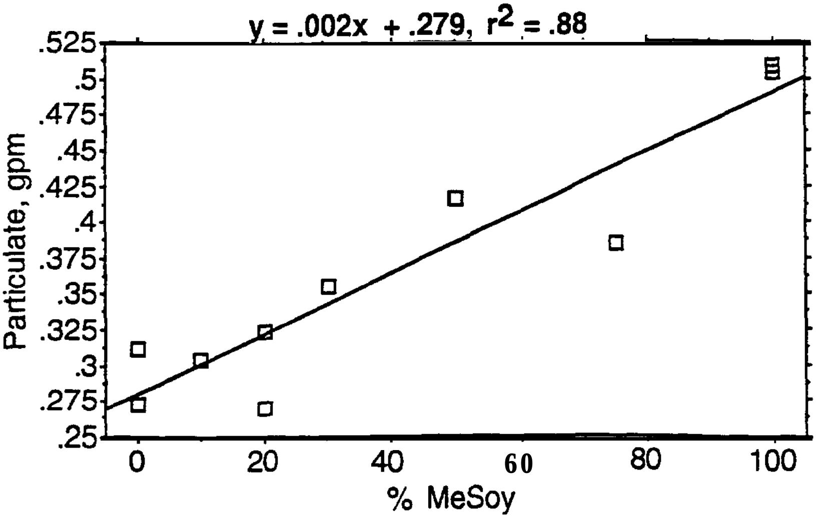

Figure 9. - Particulate emissions versus methyl soyate concentration - Cummins 5.9L engine.

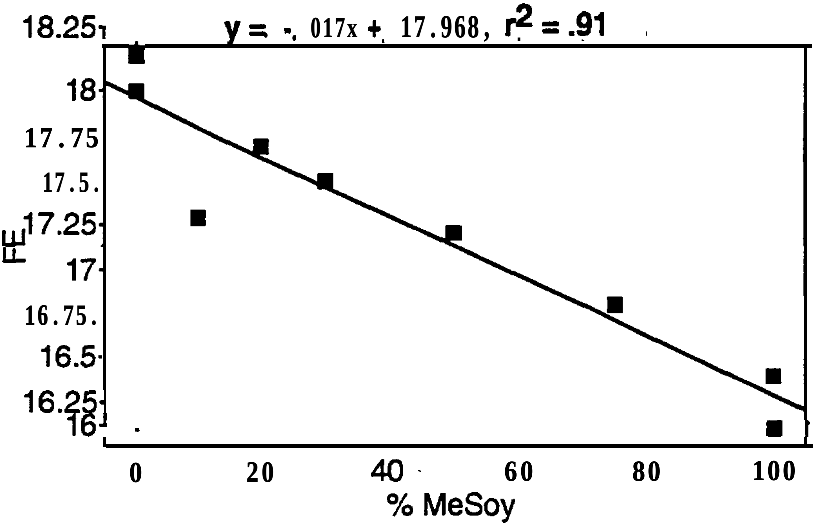

**Figure 10. - Fuel economy (mpg) versus methyl soyate concentration - Cummins 5.9L engine.**

Section III.

## Coordination

Coordination activities have included a number of meetings and presentations. These include:

- November 3, 1992; Ann Arbor; EPA Input on Biodiesel Test Plan. Ray Anderson, NIPER; Jerry Allsup, DOE; Peter Caffrey and Susan Stefanek, EPA.
- November 6, 1992; Washington; ad hoc Biodiesel Coordinating Council. John Russell and Steve Goguen, DOE; Ray Anderson and Bill Marshall, NIPER.
- November 6, 1992, Washington: ad hoc Biodiesel Coordinating Council; Roger Conway et al., Department of Agriculture; Ray Anderson and Bill Marshall, NIPER.
- December 18, 1992; AM Arbor, NSDB and EPA; ad hoc Biodiesel Coordinating Council; Bill Marshall, NIPER.
- January 11, 1993; St. Louis, NSDB; Bill Marshall, NIPER
- March 5, 1993; Washington, NSDB; NSDB Research Committee; Ray Anderson, NIPER.
- March 16, 1993; Fayetteville, AK; Razorback Transit; Discussion biodiesel demonstration. Frank Scott and Bill Riley, Razorback Transit; Bill Ayres, Interchem; Trent Roberts, American Soybean Association; Bill Marshall, NIPER.
- April 17-18, 1993; St. Louis, NSDB; Ray Anderson, NIPER.
- July 29, 1993; Denver, NSDB; Bill Marshall, NIPER.
- August 6, 1993, St. Louis, NSDB; Bill Marshall, NIPER
- September 6, 1993, St. Louis, NSDB Research Committee; Bill Marshall, NIPER.
- September 15, 1993; Warren, MI; Researchers/Testers/Users Information Exchange; Bill Marshall, NIPER
- December 9, 1993, Detroit, NSDB, Bill Marshall, NIPER.
- January 4, 1994, St. Louis, NSDB, Bill Marshall, NIPER.