SHORT-TERM PERFORMANCE OF DIESEL OIL AND SUNFLOWER OIL MIXTURES IN DIESEL ENGINES

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Investigation of the effects of sunflower oil and methyl ester when used in diesel engines was performed in two parts.The first part took place in the Department of Agricultural Engineering at North Dakota State University; the second part occurred at the Allis-Chalmers Engine Division in Harvey, Illinois.

Fuel properties and characteristics

The fuels used in the Fargo tests in addition to #2 diesel fuel were refined sunflower oil, crude sunflower oil, and five blends of each of these fuels with #2 diesel fuel (Table 1). The percent by volume of each of these fuels blended with diesel fuel was 10, 25, 50, 75 and 90. The refined sunflower oil was alkali refined and winterized. The crude sunflower oil was extracted and filtered at NDSU.

The fuels utilized in the Harvey tests were #2 diesel, 100% alkali refined sunflower oil, a blend by volume of 50% sunflower oil and 50% #2 diesel fuel, and methyl ester (Table 2).

All fuels were obtained from commercial sources with the exception of the crude sunflower oil used in the Fargo tests. The methyl ester was made from erucic-acid-free rapeseed. No additives were used. All fuels were filtered through a 5 m filter prior to using.

Samples of all fuels which were used in the tests were analyzed using American Society for Testing and Materials (ASTM) standard procedures for petroleum fuel products. Tables 1 and 2 show three important properties of the fuels which influenced engine performance: 1) The API gravity of the non-petroleum based fuels was found to be lower than the #2 diesel fuel. 2) The viscosity of the sunflower oil was significantly higher than that found for the #2 diesel fuel. 3) The #2 diesel fuel had the highest heating value of the tests fuels. Further, thermal decomposition was observed at a relatively low

Table 1. Test Fuel Properties; Fargo, ND Tests

	No. 2 Diesel	100% Sunoil Refined	100% Sunoil Crude/Filtered	75% Diesel 25% Sunoil	50% Diesel 50% Sunoil	25% Diesel 75% Sunoil
API Gravity @60°F (degrees)	35.3	22.1	21.6	32.3	29.1	25.4
Cetane Rating	48.0	31.7	27.9	—	38.2	—
Heating Value (Btu/lb)						
Gross	19,451	17,141	17,048	18,840	18,112	17,594
Net	18,271	16,061	15,995	—	—	—
Heating Value (Btu/gal)						
Gross	137,810	132,030	131,313	136,156	133,609	132,723
Net	129,447	123,707	123,197	—	—	—
Pour Point (°F)	-58	—	16	4	2	6
Cloud Point (°F)	1	—	20	4	8	13
Viscosity (cSt)						
32°F	6.42	—	187.68	15.05	34.53	71.66
100°F	2.40	—	34.33	4.74	9.64	17.37
160°F	1.48	—	14.93	2.67	4.78	8.21

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percentage level for the sunflower oil, the 50/50 blend, and methyl ester (Fig. 1) which can result in carbon buildup.

One of the problems associated with the use of sunflower oil as a fuel is that it has a pour point of -10°F (-23°C) as compared to a -35°F (-37°C) pour point for #2 diesel fuel (Table 2). Hence, sunflower oil could be used only in mild or warm weather in northern parts of the United States. However, this may not be as much of a problem as it might seem to be. For example, the temperature normals for Fargo, North Dakota are shown by months in Table 3. It can be seen that the mean minimum temperature in North Dakota is higher than the pour point of sunflower oil for all months of the year. So, the problem of a relatively high pour point for sunflower oil as compared to #2 diesel fuel would not prohibit the use of sunflower oil as a diesel fuel in North Dakota.

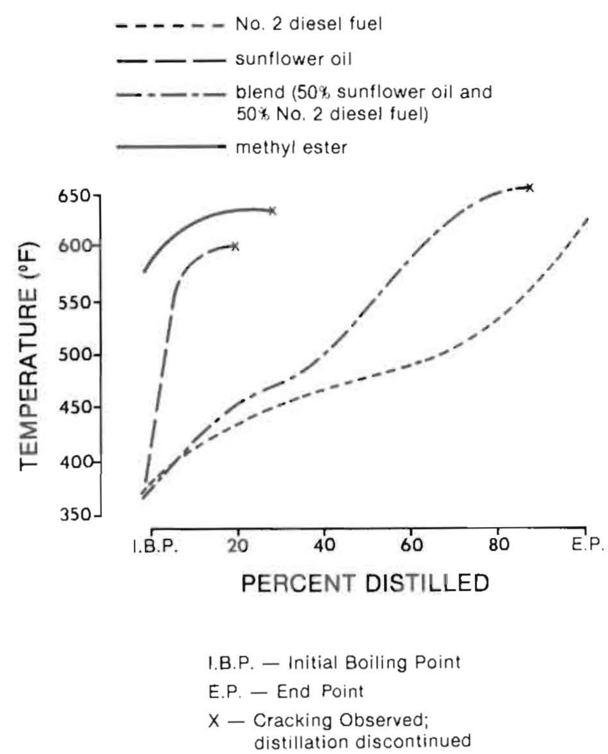


Fig. 1. Fuel Distillation Curves

Performance tests on engines in Fargo, N.D.

The first part observed diesel engine performance using four loads (50 and 75 percent of rated load, rated load, and maximum torque), seven diesel fuel/sunflower oil blends (0, 10, 25, 50, 75, 90 and 100 percent sunflower oil) and two degrees of vegetable oil refinement (crude and refined). All tests were conducted at wide open throttle. The 50 percent and 75 percent loads were determined as a percentage of the torque achieved at rated speed for each fuel. Two replications were run at each load. The order in which the tests were run was randomly selected. All tests were 10 minutes in length.

Table 2. Test Fuel Properties; Harvey, IL Tests

	No. 2 Diesel	100% Sunoil Alkali Refined	50% Diesel 50% Sunoil	Methyl Ester
Pour Point (°F)	-35	-10	-10	15
Cloud Point (°F)	-18	18	-4	24
API Gravity @60°F (degrees)	34.2	21.7	29.3	28.5
Heating Value (Btu/lb)				
Gross	19,232	16,974	18,411	17,169
Net	18,157	15,914	17,272	16,083
Heating Value (Btu/gal)				
Gross	137,369	130,530	134,882	126,415
Net	129,182	122,379	126,537	118,422
Ash (%)	<.01	<.01	<.01	<.01
Carbon (%)	87.04	78.13	83.88	77.39
Hydrogen (%)	12.78	11.62	12.48	11.90
Nitrogen (%)	—	.01	.01	.034
Oxygen (%) (By difference)	—	10.24	4.00	10.68
Sulfur (%)	.24	< 50 ppm	.13	< 50 ppm
Water & Sediment	Trace	Trace	Trace	Trace
Karl Fischer Water (ppm)	466	525	109	308
Filtration Cleanliness				
Total Particulate (ppm)	3.107	2.98	3.59	1.606
Non Combustible Particulate (ppm)	.254	2.43	.190	.254
Viscosity at 100°F (cSt)	2.08	29.40	5.80	4.33

Table 3. Monthly normal temperatures, 1974-1970 in Fargo, N.D.

Month	Mean Min	Mean	Mean Max
January	-3.6	5.9	15.4
February	0.8	10.7	20.6
March	14.9	24.2	33.5
April	31.9	42.3	52.6
May	42.3	54.6	66.8
June	53.4	64.7	75.9
July	58.6	70.7	82.8
August	56.8	69.2	81.6
September	46.2	57.9	69.6
October	35.5	47.0	58.4
November	20.0	28.6	37.2
December	4.1	13.0	21.9

References: Local Climatological Date: Fargo, N.D.; Annual Summary 1980; U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Asheville, N.C.

Performance tests were run on an Allis-Chalmers 7010 and a Ford 7000 diesel tractor. Both tractors were tested with manufacturer's standard equipment. No modifications were made to the engines before or during the tests. This simulated the practical situation when a dedicated engine for diesel fuel use would operate instead with a fuel blend containing sunflower oil or with pure sunflower oil. The Allis-Chalmers 7010 was equipped with a direct injection turbocharged six cylinder diesel engine, model 649T. The displacement of the engine was 300 cubic inches with 3.875 inches bore and 4.25 inches stroke. It had a 16.25:1 compression ratio. The injection pump was a Stanadyne Roosa Master distributor type DM4. The injection nozzles were Robert Bosch with four 0.0125 inch diameter orifices, a 0.043 inch sac length, and a 0.039 inch sac diameter. The opening pressure of the nozzles was 3830 psi. Static injection timing was 18° before top dead center (BTDC). The Ford 7000 was equipped with a direct-injection turbocharged four cylinder diesel engine, model 5609A. The displacement of the engine is 256 cubic inches with a 4.40 inch bore and a 4.20 inch stroke. It had a 16.5:1 compression ratio. A Simms in-line injection pump was used. The injection nozzles were Simms with four 0.0134 inch diameter orifices. The opening pressure of the nozzles was 3250 psi. Static injection timing was 19° BTDC.

The tractors were loaded at the PTO shaft by a M&W Gear Co. water brake dyanamometer, model P-4450. The dynamometer was equipped with an electronic digital readout for PTO torque and rpm.

Tests were run at full load, rated speed on 100 percent #2 diesel fuel at the beginning and the end of the day to assure that the engine performance remained consistent through the day and that the non-petroleum fuels had no short term effects on the engines. Each time the engine's fuel supply was switched to a different fuel the engine was run for 10 minutes at rated speed and load to allow for purging of the fuel system before starting the next test.

Fuel consumption was measured on a weight basis, temperatures were sampled at three-minute intervals from the start of the test, and three smoke samples were taken and the average reading recorded. Barometer readings were taken at the beginning and the end of each test period and used to correct the engine performance data to standard atmospheric conditions.

Performance tests on engine at Harvey, Illinois

The second part of this investigation measured diesel engine performance at four speeds (1800 rpm, 2000 rpm, 2200 rpm, and 2300 rpm), five loads (25, 50, 75, 100 and 110 percent of the rated torque at 2300 rpm) and four fuels (#2 diesel, 100 percent sunflower oil, 100 percent methyl ester, and a 50 percent blend by volume of sunflower oil in #2 diesel fuel).

A direct injection, intercooled, turbocharged, four-cylinder Allis-Chalmers diesel engine, model 4331, was selected because of typical design and relatively low fuel consumption. A multi-cylinder engine was chosen in order to test cylinder to cylinder variations in future endurance tests. The displacement of the engine was 200 inches cubed with a 3.875 inch bore and a 4.25 inch stroke. It had a 14.1:1 compression ratio.

Due to the higher viscosity of the blend and 100 percent sunflower oil, slight modifications were made to the fuel system to maintain the manufacturer's specified transfer pump pressure of 90 ± 5 psi (620 ± 35 kPa) at 2300 rpm. For the blend, a second fuel filter in parallel to the existing filter was added. For the sunflower oil, an auxilliary fuel system supply pump was also added. One set of tests was run on the sunflower oil with no fuel system modifications to compare the results with the modified system. No modifications were necessary when using the methyl ester fuel. The injection pump was calibrated to factory specifications for #2 diesel fuel and was not recalibrated during the tests. Static injection timing was 18° BTDC. A dynamic timing advance of 14° was maintained for all tests.

Tests on 100 percent #2 diesel fuel were run at the beginning and the end of the day, as in the Fargo tests. The engine was run at rated speed and load for 20 minutes to allow for purging of the fuel system before starting a test on a different fuel. Twenty minutes were needed because of the length of the fuel supply line and the low fuel consumption rate of the engine. A chemical analysis of the fuel composition in the return line after the 20 minutes purging process was performed. When sunflower oil was used there was no diesel fuel remaining in the fuel return line. When methyl ester was used, there was 0.7 percent by volume of diesel fuel remaining in the fuel line after the 20 minute purging process.

In addition to typical engine performance parameters, cylinder pressure was measured. All tests conformed to SAE standards. The engine performance data for these tests were also corrected to standard atmospheric conditions.

RESULTS AND DISCUSSIONS

Engine Performance Tests at Fargo, N.D.

For purpose of emphasizing the difference in various parameters of engine performance as a function of blend composition relative curves are used throughout this part of the engine analysis.

Engine test results for the Ford 7000 are presented in Figure 2. Only results at rated load are shown. The results at other loads were similar. Engine power was 81.5 hp on diesel fuel and decreased as blends with higher concentrations of sunflower oil were used. Engine power was reduced 9 percent when 100 percent sunflower oil was used. Volumetric fuel efficiency was 15.5 HP-HR/GAL and decreased as higher concentrations of sunflower oil were used. When 100 percent sunflower oil was used, the volumetric fuel efficiency decreased 5.4 percent.

A more satisfactory way to compare the performance of the test fuels is to compare the thermal efficiency (TE). In the Ford 7000 engine, the TE was 31.2% and decreased as higher percentages of sunflower oil were used. The TE was 3.5 percent lower when using 100 percent sunflower oil. Engine

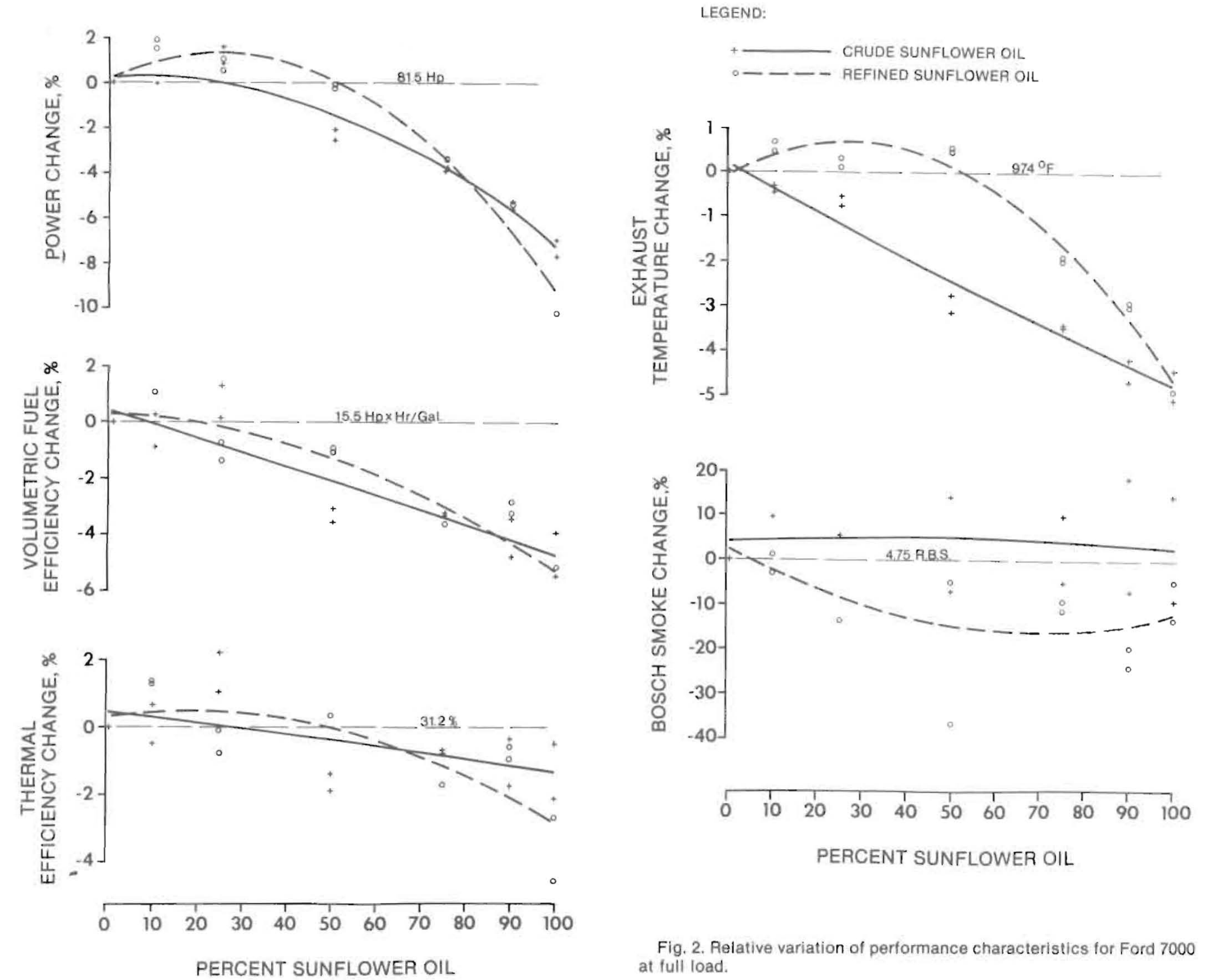


Fig. 2. Relative variation of performance characteristics for Ford 7000 at full load.

exhaust temperatures was 974°F on diesel fuel and decreased as the percentage of sunflower oil in the fuel blend increased. The engine exhaust temperature was 47°F lower when 100 percent sunflower oil was used. Bosch smoke readings were also taken but the variability was high. The Bosch smoke number was 4.75 while using diesel fuel and appeared to decrease slightly with increased sunflower oil concentration. For all performance variables, the trends were similar for both the crude and refined sunflower oil.

Engine test results for the Allis-Chalmers (A-C) 7010 are presented in Fig. 3. Again, only the results of the tests at rated load are shown. The results at the other loads were similar. Engine power was 98.6 hp while using diesel fuel and varied when using sunflower oil blends. The engine delivered the most power when a 75/25 SFO/Diesel fuel blend was used. With this fuel blend, the engine produced 6.2 percent more power than when using #2 diesel fuel. Volumetric fuel efficiency was 13.86 HP-HR/GAL while using diesel fuel and decreased with increasing sunflower oil concentrations in the test fuel. The thermal efficiency was 27.2 percent while using diesel fuel and increased 0.6 percent when 100 percent sunflower oil was used. Engine exhaust temperature was 1079°F while using diesel fuel and was highest for the intermediate concentrations of sunflower oil in the test fuel blend. Bosch smoke readings were 2.85 while using diesel fuel and were variable. The tendency for both the exhaust temperature and Bosch smoke readings was to follow the power output of the engine.

Combining test results from both engines, the following trends emerge: 1) the degree of fuel refinement has little or no effect on engine power output, volumetric fuel efficiency, thermal efficiency and exhaust temperature. This would be expected since the crude and refined sunflower oil fuels have comparable energy contents.

2) The quantity of sunflower oil in the fuel blend affected the power output of the engine. The volumetric efficiency decreased when sunflower oil was

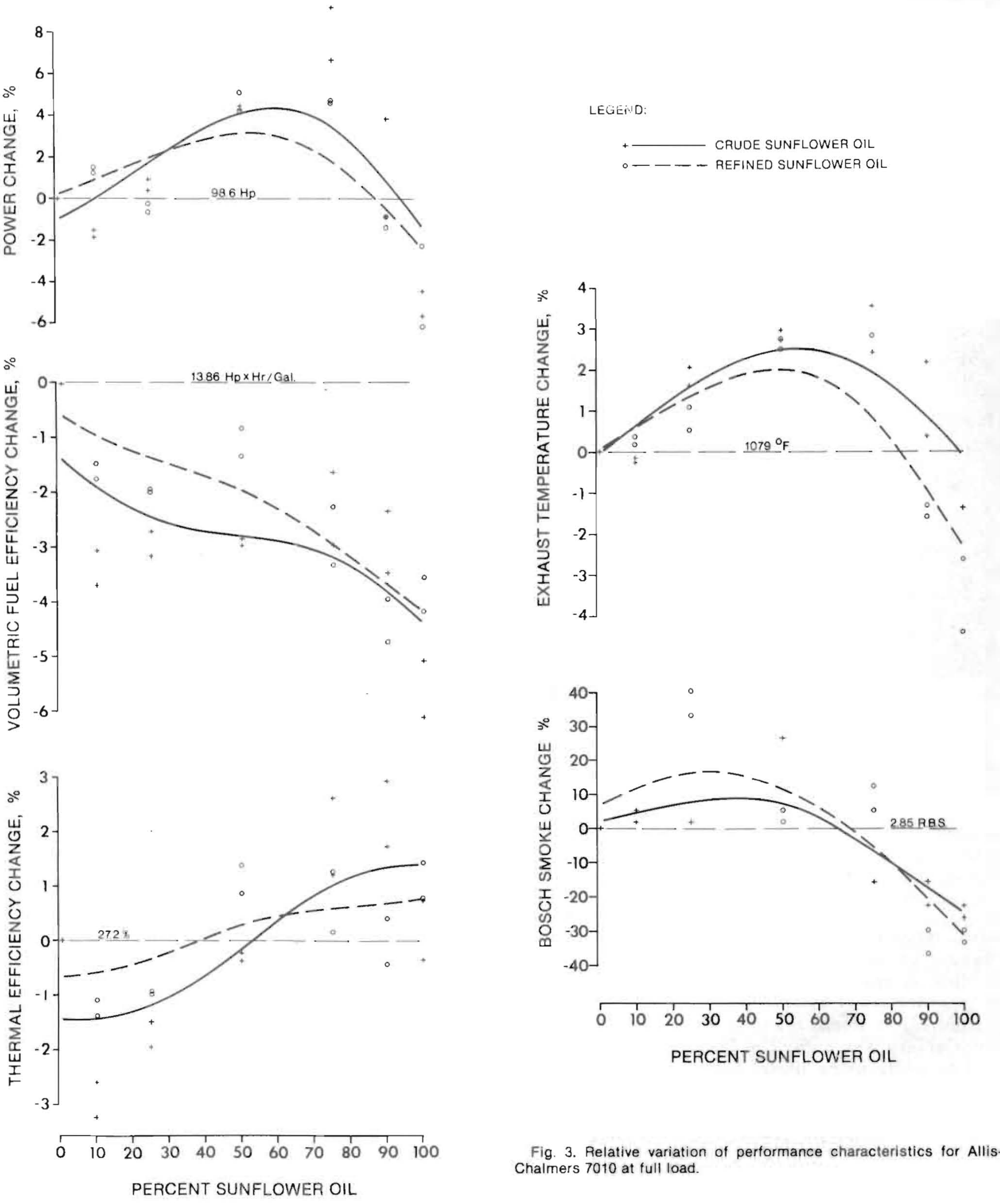


Fig. 3. Relative variation of performance characteristics for Allis-Chalmers 7010 at full load.

substituted for the #2 diesel fuel. The differences when using 100 percent sunflower oil as compared to #2 diesel fuel were 5 percent. These differences are about the same as the 6 percent difference in volumetric energy content of the two fuels. The differences in thermal efficiency for differing concentrations of sunflower oil in diesel fuel were small but significant. These two engines gave differing thermal efficiencies when sunflower oil was used as fuel.

Factors which might explain the differing thermal efficiencies may be the dissimilar injection pumps, injectors, compression ratios, or combustion chamber designs. There was a general decrease in Bosch smoke number as sunflower oil was substituted for #2 diesel fuel in the test fuel blend.

Engine performance tests at Harvey, Illinois

Engine performance results for rated load and rated speed are presented in Figs. 4 and 5. Results for other loads and speeds were similar. Using the power output on diesel fuel as a baseline, the 50-50 blend gave about 3.1 percent more power than diesel fuel and the methyl ester produced about 5.8 percent less power than diesel fuel. The volumetric fuel efficiency of sunflower oil, the blend, and the methyl ester was lower than the #2 diesel fuel volumetric fuel efficiency because of a difference in energy content. The thermal efficiency for the sunflower oil and the methyl ester was higher than for #2 diesel fuel. The fuel flow rate (gal/h) to the injection nozzle changed as the density and viscosity of the test fuels changed. The volumetric fuel flow was higher for the nonpetroleum fuels compared to #2 diesel fuel. Higher flow resistance for more viscous sunflower oil was compensated by less internal leakage in the injection pump. The methyl ester and the blend had higher internal leakage but less flow resistance than the sunflower oil because of a lower viscosity. This lower flow resistance caused higher fuel flow for methyl ester compared to sunflower oil. The higher exhaust temperature of the #2 diesel fuel and the blend resulted from a lower thermal efficiency. Higher exhaust temperatures for the #2 diesel fuel and the blend caused higher turbocharging speed providing more air. This increased air could act to improve fuel-air mixing and combustion; however, exhaust smoke for the #2 diesel fuel and the blend is higher than the other two test fuels. Methyl ester produced the lowest exhaust smoke.

While using 100 percent sunflower oil, experiments were carried out with modifications to the fuel line to maintain the manufacturer's specified transfer pump pressure of 90 ± 5 psi at 2300 rpm. With the standard fuel line and filter while using 100 percent sunflower oil, the transfer pump pressure dropped to 80 psi at rated torque and 2300 rpm. The fuel system was modified to include a second fuel system supply pump to maintain the proper transfer pump pressure. Further, the lower transfer pump pressure did not cause any changes in timing advance. The engine power output, volumetric fuel efficiency, and thermal efficiency for the standard system was lower than for the modified system (Fig.7).

SUMMARY AND CONCLUSIONS

Engine performance tests at Fargo, N.D.

The following conclusions were drawn from the test results:

1. Volumetric fuel efficiency was decreased as the quality of sunflower oil in the fuel blend was increased. This increase parallels the differences in energy content of the two fuels.

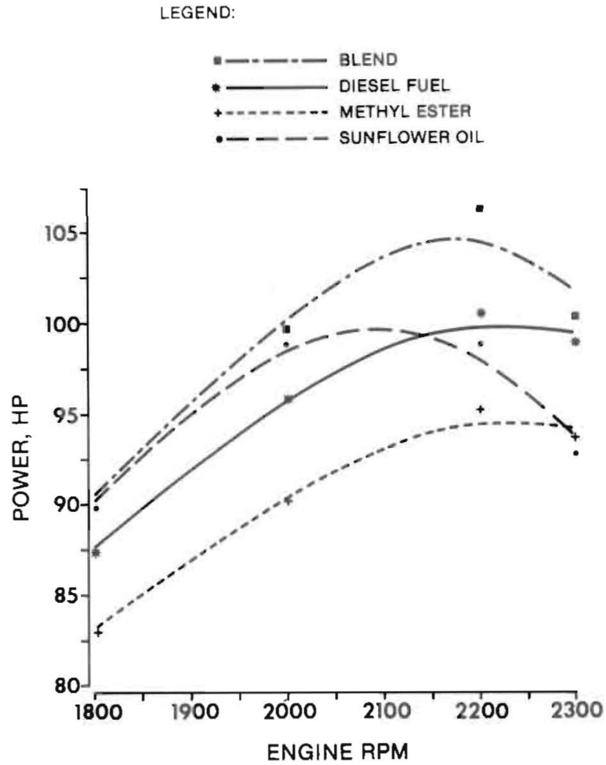


Fig. 4. Allis-Chalmers 433I engine power output at 100% load.

2. The thermal efficiency varied as the quantity of sunflower oil in the fuel blend was changed. In the Ford 7000 the thermal efficiency decreased while in the Allis-Chalmers 7010 it increased. This indicates that various engines will respond differently.

3. Differences in engine exhaust temperatures were measured when the amount of the sunflower oil in the test fuel was varied. Exhaust temperatures decreased for the Ford 7000 engine with increased percentages of sunflower oil, but for the Allis-Chalmers 7010 engine the temperature increased initially and then decreased.

4. Exhaust smoke readings decrease slightly as sunflower oil was substituted for #2 diesel fuel. The smoke reading results follow the exhaust temperatures trends for both engines.

5. Engine power output, volumetric fuel efficiency and thermal efficiency showed mixed results due to the degree of sunflower oil refinement. Generally, there was no effect on the Ford 7000 engine but results were not conclusive on the Allis-Chalmers 7010 engine.

Engine performance tests at Harvey, Illinois

A direct injection, turbocharged, intercooled, four cylinder diesel engine was tested. Four fuels (#2 diesel fuel, alkali refined sunflower oil, a 50 percent

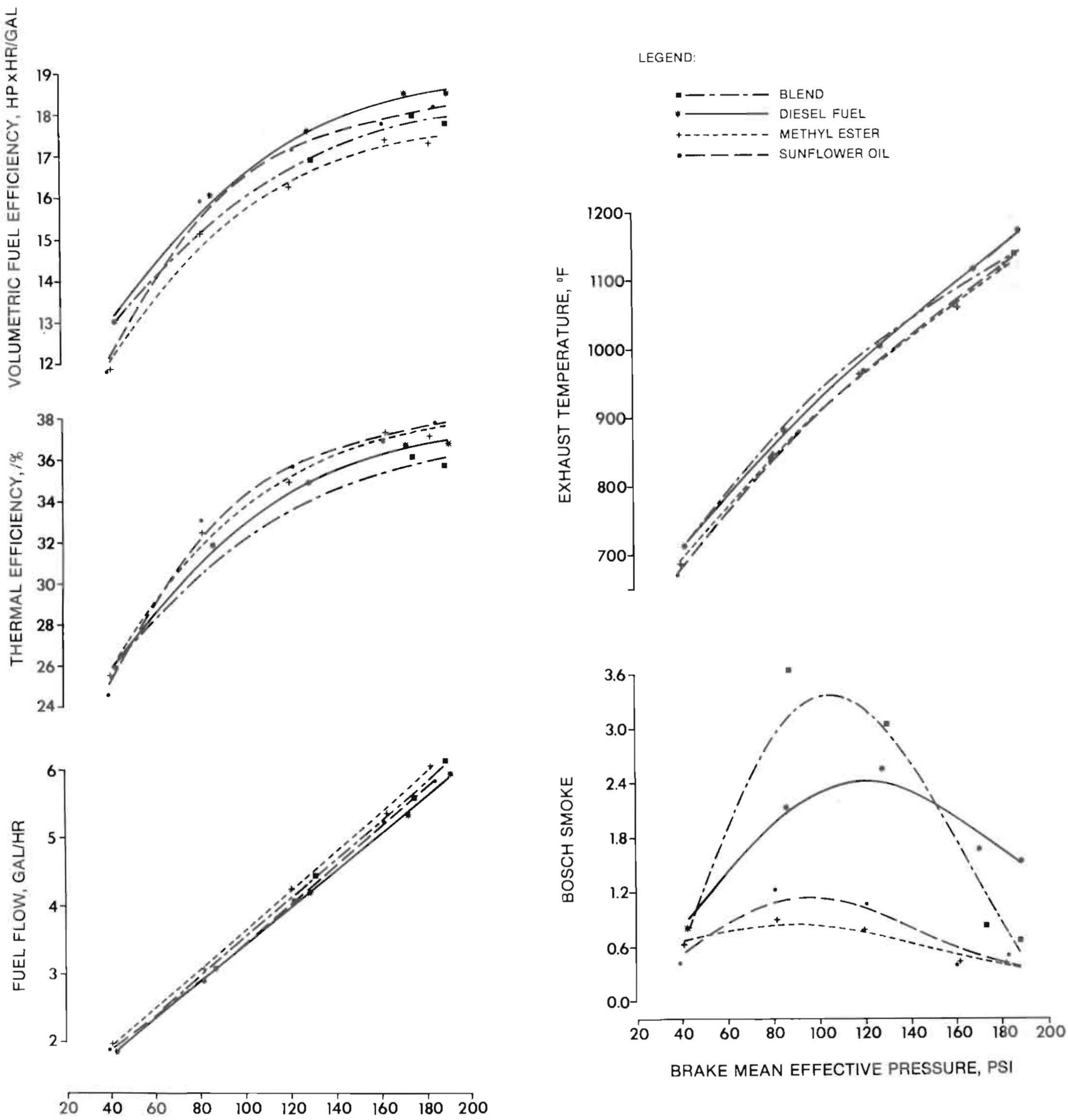
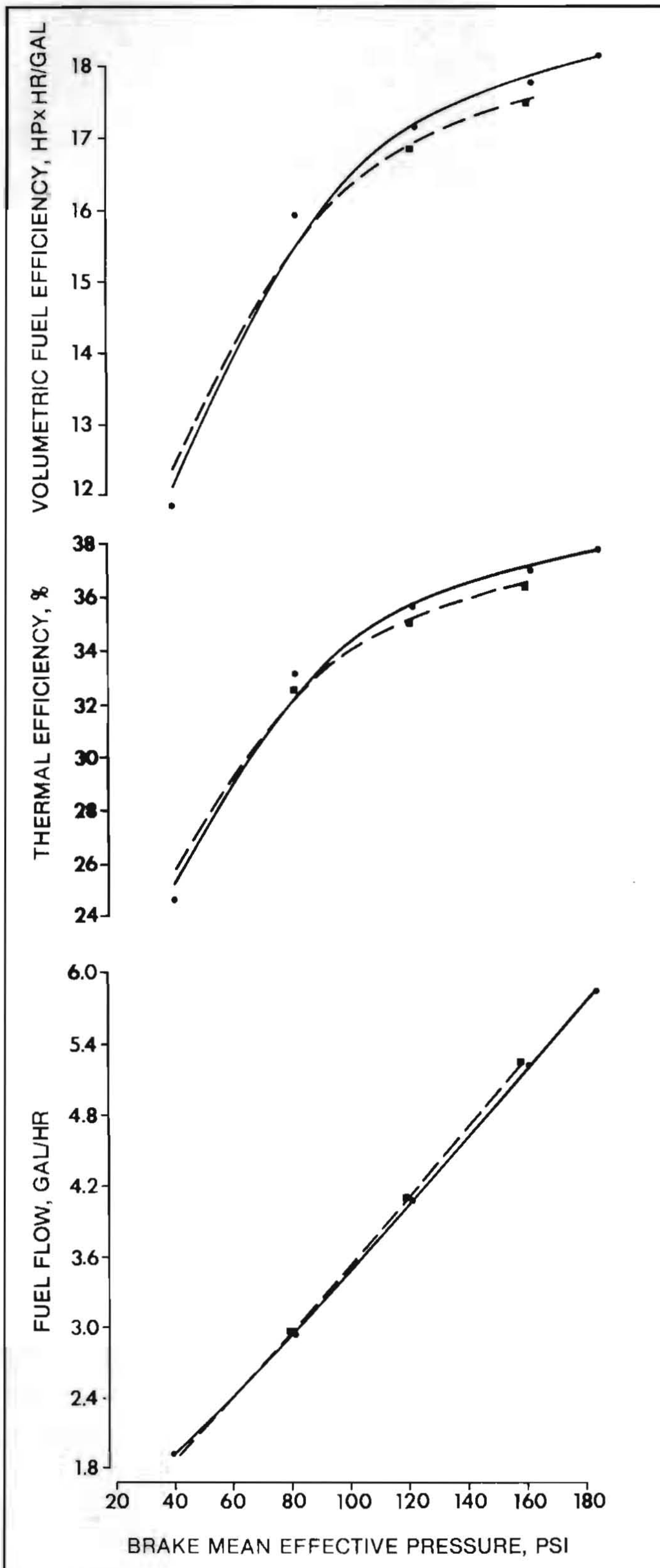


Fig. 5. Allis-Chalmers 4331 engine performance at 2300 RPM.

blend by volume of sunflower oil and #2 diesel fuel, and methyl ester) were tested at four engine speeds and five engine load.

The following conclusions were drawn from the test results:

1. Volumetric fuel efficiency was lower for the sunflower oil, blend, and methyl ester as compared to #2 diesel fuel. This reflects differences in energy content of the test fuels.
2. Thermal efficiency for the sunflower oil and the methyl ester was higher than the #2 diesel fuel.
3. The volumetric fuel flow rate was higher for the sunflower oil, blend, and methyl ester compared to #2 diesel fuel possibly reflecting the different viscosity and density of the fuels.



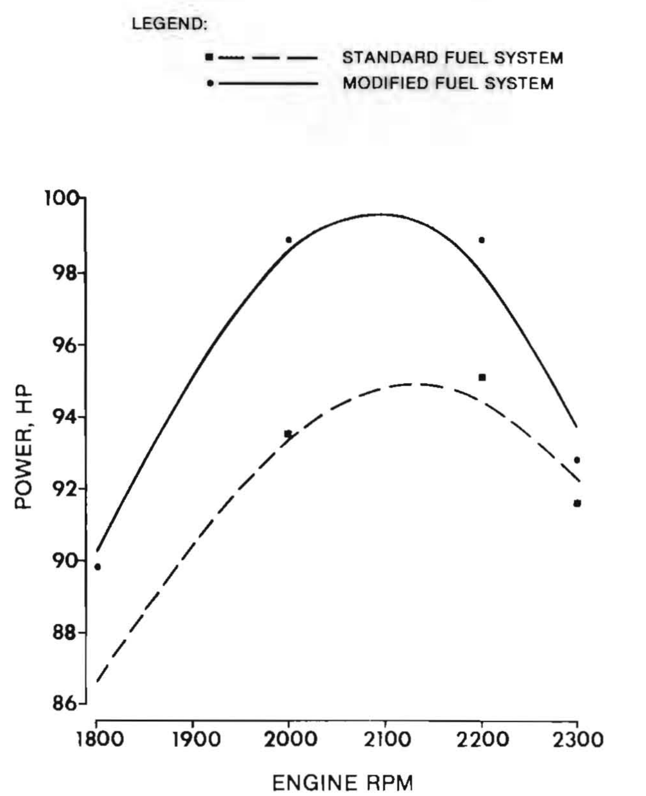


Fig. 6. Allis-Chalmers 4331 engine performance while using 100% sunflower oil in two fuel supply systems.

4. The highest exhaust temperatures were recorded when using #2 diesel fuel and the blend. This may be due to the lower thermal efficiency of these fuels.
5. Exhaust smoke was higher for the #2 diesel fuel and the blend as compared to the sunflower oil and the methyl ester. The lowest exhaust smoke was observed when using methyl ester.
6. Modifications to the fuel supply system were necessary to maintain the manufacturer's specified transfer pump pressure when using pure sunflower oil due to the higher viscosity of the sunflower oil.
7. The engine power, volumetric fuel efficiency and thermal efficiency were lower when using sunflower oil in the standard fuel supply system as compared to the modified fuel supply system.

Overall

The performance of a diesel engine while using sunflower oil or methyl ester is comparable to the performance when using #2 diesel fuel with a few differences. These differences may be explained by the different physical and chemical properties of the fuels and different engine designs.

Additional testing is needed before any conclusions can be drawn concerning the long term effects of using vegetable oils in a diesel engine.

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