♣Engine Durability Screening Test of a Diesel Oil/Soy Oil/Alcohol Microemulsion Fuel

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ABSTRACT

A hybrid fuel and No. 2 diesel fuel were burned in direct-injection diesel engines to compare the effects of the fuels on engine durability. The hybrid fuel was a microemulsion of soybean oil, diesel fuel, 190-proof ethanol and 1-butanol. The engines were run for 200 hr on each fuel with loads and speeds controlled by computer according to a cycle suggested by the EMA (Engine Manufacturer's Association). Engines were disassembled before and after the runs to determine the difference in wear and carbon deposits. The engine running on the hybrid fuel completed the 200-hr EMA test without difficulty. The hybrid produced less engine wear than diesel fuel, but produced greater deposits of carbon and lacquer on the injector tips, intake valves and tops of the cylinder liners. Also, engine performance was degraded ca. 5% at the end of the 200-hr test.

INTRODUCTION

Renewable fuels derived from vegetable oils are capable of providing good engine performance in the short term (1-4). In more extended operations, the same fuels can cause degradation of engine performance, excessive carbon and lacquer deposits and actual damage to the engine. The probability of such problems occurring is influenced by the loads and speeds to which the engine is subjected. The Engine Manufacturer's Association (EMA) has designed a standard 200-hr test for preliminary evaluation of the effects of alternative fuels on the durability of diesel engines (5). The cycle includes 60 min at rated load and speed, 60 min in a lugged condition, 30 min under light load and 30 min at low idle. The above cycle is repeated 5 times and then the engine is stopped for a 9-hr cooling period. The above daily sequence is continued for 13.3 days. If fuels pass this preliminary screening, engine manufacturers will undoubtedly want to carry out more extensive in-house tests before extending warranty coverage to engines burning such fuels.

The objectives of the tests reported herein were to carry out the EMA 200-hr test on No. 2 diesel fuel to provide baseline data and to carry out the same test on an experimental fuel identified as Shipp Nonionic.

EQUIPMENT AND MATERIALS

Dynamometer and Controller

A special controller was designed and developed to carry out the EMA cycle. The controller was based on a type Z80, model 2810 microcomputer (Zilog, Inc., Cupertino, California). An AW model 400 portable, cradle dynamometer (AW Company, Colfax, Illinois) was used to provide engine loads. Circuits were designed so the computer would sense the load on the dynamometer torque arm and regulate the torque by changing the pressure on the brake shoes in the dynamometer's rotating drum. Other circuits were designed to sense the dynamometer speed with a magnetic pickup and to control the engine governor setting with a stepping motor. A keyboard permitted daily input of the rated engine torque and speed. The computer was programmed to base other points in the EMA cycle on the rated torque and speed. Circuits were designed to permit the computer to detect various engine or dynamometer malfunctions and to safely shut down the system. If no malfunctions occurred, the computer was programmed to repeat the basic 4-step cycle 5 times (for a total of 15 hr) and then shut down the system.

The controller was designed to run in either the manual or automatic mode. Torque and speed were controlled manually in manual mode and instantaneous values of torque, speed and power were printed on keyboard command. In the automatic mode, torque and speed were controlled by the programmed cycle and 5-min averages of torque, speed and power were printed every 5 min. The system was designed to flag 5% power losses and to shut down if a 10% power loss occurred.

Instruments

Temperatures at critical points in the engine were measured with chromel-alumel thermocouples and observed manually with a model 199 digital indicator (Omega Engineering Co., Stanford, CT). The observed temperatures included exhaust gas, coolant, return fuel, lubricating oil in the pan and air in the intake manifold. A hygrothermograph was used to indicate temperature and humidity in the test cell and a barometer was used to indicate atmospheric pressure.

A surge chamber and rotameter were used for blow-by indication. The readings were not corrected for gas temperature and are approximate. The rotameter did not become available until after the test on diesel fuel.

A calibrated Model 1037 microscope (American Optical Company, Buffalo, NY) was modified so that injection nozzles could be mounted on the microscope stage. The microscope was used to inspect and photograph injector tips and to measure orifice diameters.

Fuel Handling Equipment

Engine fuel was mixed in a specially designed mixing tank and then pumped into a 190 L (50 gal) drum. During automatic operation, the engine withdrew fuel directly from the drum. When performance tests were being conducted in the manual mode, the engine withdrew fuel from an automatic system for measuring elapsed time while 200 g of fuel were being consumed.

Engines

Two identical Deere, model 4219 D, 3.589 L engines (Deere & Co., Moline, Illinois) were used. They were rated at 41.8 kW continuously at 2200 rev/min and had compression ratios of 16.3:1. Both engines were fitted with turbochargers before the tests. For convenience in record keeping, one engine was labeled A and the other B.

Fuels

Commercial-grade diesel fuel was used as the reference fuel because it was much less expensive than Phillips 2D reference fuel. A representative sample of the commercial fuel was sent to Phoenix Chemical Laboratory for testing and its properties are shown in Table I. The commercial fuel is identified as D2.

The experimental fuel was a nonionic microemulsion developed by Dr. A.W. Schwab at the USDA laboratory in

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[1] Presented at the American Oil Chemists' Society meeting in Chicago, May 1983.

Properties		Hydrocarbon Types	
API gravity @ 15.6°C	35.5	Saturates	81.1%
Sulphur, % (x-ray)	0.14	Olefins	0.0%
Copper Corrosion (D130)	1a	Aromatics	18.9%
Flash point, °C (D93)	62.2	Carbon	86.61%
Pour point, °C	-34.3	Hydrogen	13.20%
Cloud point, °C	-15.6	C/H ratio	6.56
Gross heat, kJ/kg	45529		
Water & Sediment, %v	0.0005	Distillation Data:	
Ramsbottom Carbon on 10% res	0.01%		
Viscosity @ 40°C, mm^2/s	2.82	IBP	176°C
Cetane No.	51.4	10%	219°C
		50%	266°C
		90%	316°C
		End Pt.	334°C
		Recovery	98%
		Residue	1.7%

TABLE II

Composition of Shipp Nonionic (SNI) Fuel

Component	% by volume
No. 2 diesel fuel	50
Degummed, alkali-refined soybean oil	25
190-proof ethanol	5
1-Butanol	20

TABLE III

Properties of Shipp Nonionic Fuel

Property	Value
Viscosity @ 38°C, mm^2/s	4.03*
Stability @ 5°C, hours	> 24
Higher Heating Value, kJ/kg	41263
Stoichiometric Air-Fuel Ratio	13.1
Flash point, °C	28.3
Ramsbottom Carbon Residue, % of whole sample	0.14
Cetane No.	34.7**

*Three sample average, i.e.
USDA NRRC; 3.69 mm^2/s
Phoenix Lab, sample 1: 4.14 mm^2/s
Phoenix Lab, sample 2; 4.26 mm^2/s

**Three sample average from Southwest Research Institute, i.e.
Sample 1, Subsample A; 41.8 (discarded)
Sample 1, Subsample B; 34.0
Sample 2, Subsample A; 35.5
Sample 2, Subsample B; 34.6

Peoria, Illinois (private communication from E. H. Pryde to John Shipp, Shipp Implement Company, Russellville, Kentucky). Composition of the experimental fuel is given in Table II and properties are given in Table III. The experimental fuel is hereafter identified as Shipp Nonionic fuel or, more briefly, as SNI fuel.

PROCEDURE

The typical procedure was to measure engine parts, rebuilding the engine with new parts at critical points. Injection nozzle orifices were measured with the microscope and the nozzles were tested for pattern and tip and back leakage. Following a break-in period, the engine was then tested for performance over a wide range of speeds. Torque, speed, fuel consumption, critical temperatures, atmospheric conditions and blow-by were observed at each engine load. During the initial tests on D2 fuel, use of 50 g fuel increments produced excessive scatter in the fuel consumption data, and those data were later discarded. Use of 200 g fuel increments in subsequent tests gave satisfactory results.

After initial performance tests, the engine was started into the EMA test sequence. Oil samples were taken daily during the tests for viscosity measurement and additional samples were taken at 50-hr intervals for analysis of wear on metal. After 105 EMA hours, the engine was again tested for performance and the oil was changed. Performance was tested again at the end of the 200-hr sequence. The engine was disassembled and measured and the injection nozzles were retested.

Two interruptions occurred during the EMA tests of the SNI fuel. On EMA day 4, a wire became loose from vibration and caused the controller to detect the loss of dynamometer coolant pressure. The test was restarted and completed the next day. On EMA day 12, a thunderstorm caused the loss of electrical power and again the tests were resumed the next day.

RESULTS

Performance

Engine A completed 200 EMA hr on diesel fuel without difficulty. Except for changing the fuel filter at 125 EMA hr, no parts were changed. Engine B also completed 200 EMA hr on SNI fuel without difficulty and no parts were changed.

Performance parameters for Engine A running on D2 fuel are shown in Figure 1. Initial performance data are also shown in Table IV. The initial performance on D2 was essentially reproduced after 105 EMA hr and 200 EMA hr, so only one curve is shown in Figure 1 for each performance parameter. Experimental points were omitted to reduce clutter.

The performance of Engine B running on SNI fuel is also shown in Figure 1. Typical performance data are shown in Table V. The average size of individual fuel injections was not affected by the accumulation of EMA hours (Figure 1). Between 0-105 EMA hr, negligible change occurred in other performance parameters. After 200 EMA hr, however, brake mean effective pressure (BMEP) and power were reduced ca. 5%. With no change in fuel delivery, the power reduction caused a corresponding increase in brake thermal efficiency.

Figure 1 permits comparison of engine performance on SNI fuel with performance on D2 fuel. The average size of fuel injections was virtually the same for both fuels. The SNI fuel burned more efficiently over the entire speed range, but not enough to offset its smaller heating value (90.6% of that of No. 2 diesel). Thus, the BMEP and power were less for the SNI fuel than for D2.

TABLE IV

Initial Performance of Engine on Diesel Fuel

Engine Letter: B
Displacement: 3.589 Liter
EMA Hours on Engine: 0
Total Engine Hours: 19.6
Fuel Name: #2 Diesel
Gross Heat of Fuel: 45529 J/G
Barometric Pressure: 99.00 kPa
Date of Test: 12-20-82

		Temperatures Celsius				
Speed (RPM)	Blow by (L/MIN)	Intake Air	Exhaust Gas	Coolant	Oil Pan	Return Fuel
2378	49.56	48	253	81	97	50
2352	50.97	49	288	83	95	51
2315	53.80	55	355	84	96	53
2269	60.03	63	419	86	99	50
2208	60.88	69	498	87	99	52
2002	54.94	73	548	88	102	58
1814	58.05	73	568	90	106	62
1603	49.84	66	572	89	107	64
1391	45.31	61	575	89	106	63
1172	45.31	57	569	90	106	65

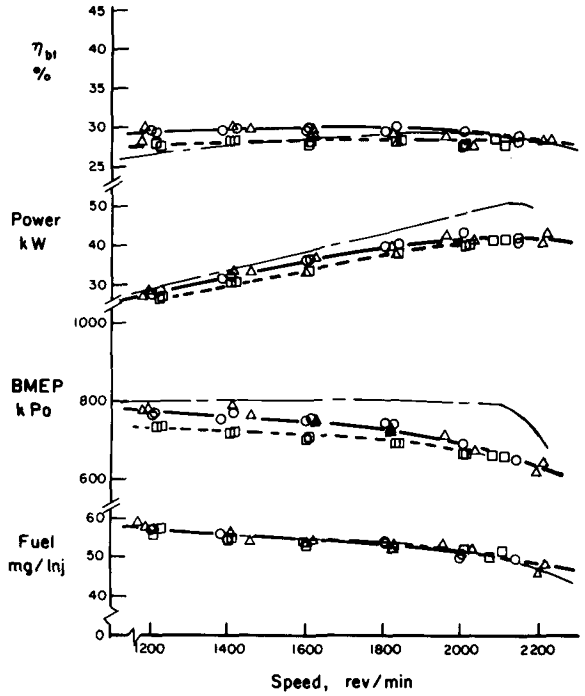

FIG. 1. Engine performance on diesel and hybrid fuels. — - — No. 2 Diesel fuel, Engine A SHIPP NONIONIC FUEL, Engine B. ○—○ 0 EMA hours; △—△ 105 EMA hours; □- - -□ 100 EMA hours.

TABLE V

Initial Performance of Engine on SNI Fuel

Engine Letter: B
Displacement: 3.589 Liter
EMA Hours on Engine: 0
Total Engine Hours: 20.1
Fuel Name: Shipp-Nonionic
Gross Heat of Fuel: 41263 J/G
Barometric Pressure: 100.00 kPa
Date of Test: 12-20-82

Speed (RPM)	Blow by (L/MIN)	Temperatures Celsius Intake Air	Exhaust Gas	Coolant	Oil Pan	Return Fuel
2375	43.89	45	246	82	98	47
2347	43.89	47	284	84	96	45
2314	46.72	52	341	85	97	46
2272	52.39	59	404	86	98	51
2148	58.05	68	481	87	99	51
2082	49.56	64	501	87	101	52
1803	49.56	65	522	88	104	56
1613	41.06	60	524	88	103	58
1384	43.89	56	530	88	103	59
1204	43.89	53	537	88	104	61

TABLE VI

Initial and Final Test Results for Injection Nozzles used with SNI Fuel

Nozzle No.	Opening Pressure Psi	Opening Pressure MPa	Leak* Time Sec.	Chatter	Tip** Leak?	Orifice Diameters, m*** A	B	C	D
			-INITIAL CONDITION-						
1	3100	21.4	12.19	VG	No	275	269	275	270
2	3100	21.4	10.53	VG	No	269	263	280	280
3	3100	21.4	12.87	VG	No	263	269	280	280
4	3150	21.7	10.90	VG	No	280	270	270	280
			-AFTER 200 HOUR TEST-						
1	2900	20.0	65.44	VG	No	0	252	220	252
2	2950	20.3	6.34	VG	No	252	51	263	248
3	2925	20.2	12.02	VG	No	252	240	60	252
4	2950	20.3	94.24	G	No	270	137	250	25

*Time required for line pressure to drop from 13.8 to 10.3 MPa.
**Test conducted with 19.3 MPa pressure trapped in nozzle.
***Each nozzle has 4 orifices spaced at 90° around the tip.

Injection Nozzles

Results of tests on injection nozzles are shown in Table VI. Test apparatus was not available in time for an initial test of the nozzles used to inject D2 fuel. However, the final tests on those nozzles after 200 EMA hr produced substantially the same results as the initial tests on the nozzles reported in Table VI. Thus, no degradation of nozzle performance occurred running 200 EMA hr on D2 fuel. Some hard carbon accumulated on the tips, but did not obstruct the orifices. In contrast, the nozzles used with SNI fuel did undergo significant changes during the 200-hr EMA test. Whereas the nozzles survived the entire 200 hr, substantial buildup of hard carbon occurred on the tips. Inspection under the microscope showed every orifice reduced in size (see Table VI) and 4 orifices partially blocked. One orifice appeared completely blocked, but every orifice was able to produce a spray pattern in the subsequent pop tests. For unknown reasons, 2 nozzles exhibited large increases in the time for back leakage to reduce line pressure from 13.8 MPa to 10.3 MPa. All 4 injectors were disassembled and, except for a brown stain on the tips, the needles were clean.

Lubricating Oil Consumption and Viscosity

Figure 2 shows oil-viscosity patterns during the EMA tests with the D2 and SNI fuels. Based on oil budget calculations, average oil consumption in Engine A (running on D2 fuel) was 31.5 mL/hr before the 100-hr oil change and 30.7 mL/hr after. Engine B, running on SNI fuel, had both dilution and consumption before the oil change, with net consumption averaging 1.3 mL/hr. Following the oil change, average consumption in Engine B was 28.1 mL/hr. No substantial changes were found for oil viscosity when burning either the D2 or SNI fuels.

Engine Wear After 200 Hours

Tables VII and VIII show weight loss in bearing as measured with a microbalance scale. Loading effect on wear

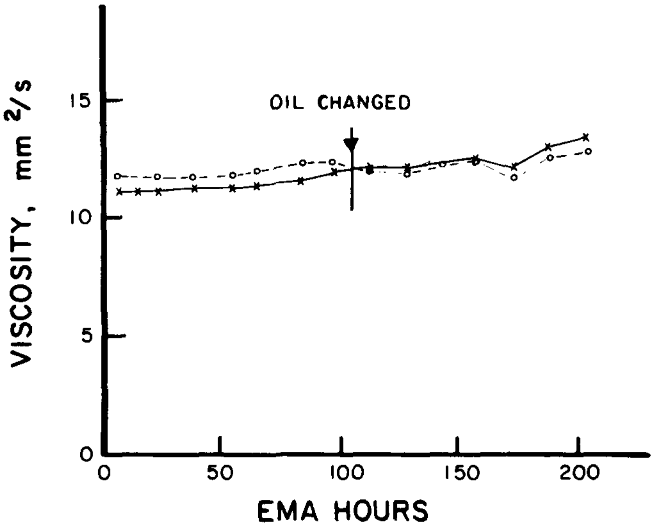

FIG. 2. Viscosity of engine lubrication oil. X–X Engine A (D2 Fuel); O- - -O Engine B (SNI fuel); oil temperature = 99 C.

TABLE VII

Main Bearing Wear

Bearing No.	1		2		3		4		5*		Ave.	
Block or Cap	B	C	B	C	B	C	B	C	B	C	B	C
mg Lost W/ D2 Fuel	24.1	31.2	26.3	35.2	29.2	35.5	30.1	34.6	45.7	55.6	31.1	38.4
W/ SNI Fuel	10.9	17.0	10.6	25.5	9.1	20.1	7.3	21.0	27.8	32.6	13.1	23.2

*Combination Radial and Thrust Bearing

TABLE VIII

Rod Bearing Wear

Cylinder No.	1		2		3		4		Ave.	
Rod or Cap	R	C	R	C	R	C	R	C	R	C
mg Lost										
W/ D2 Fuel	16.1	11.2	14.9	11.8	14.8	12.2	18.8	16.5	16.2	12.9
W/ SNI Fuel	22.3	9.0	15.5	8.9	11.9	6.1	11.0	7.4	15.2	7.9

TABLE IX

Piston Ring Wear

Cylinder No.	1			2			3			4			Ave		
Ring No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
mg Lost															
W/ D2 Fuel	28.5	-	52.3	111.0	46.6	53.3	119.0	34.0	41.2	105.1	43.6	49.2	90.0	41.1	49.0
W/ SNI Fuel	95.0	29.8	24.6	82.9	69.2	17.6	102.2	27.2	21.7	83.8	28.1	13.1	91.0	38.6	19.3

TABLE X

Probable Sources of Wear Metals

Metal	Sources
Aluminum	piston skirts, main and rod bearings
Chrome	piston pins
Copper	cam bearings, piston pin bushings
Iron	piston rings, cylinder liners
Magnesium	unknown
Nickel	main and rod bearings
Silicon	dust

TABLE XI

Weights of Carbon Deposits on Valves

Cylinder No.	1		2		3		4		Ave	
Intake or Exhaust	I	E	I	E	I	E	I	E	I	E
mg gained										
w/ D2 fuel	94.9	67.3	65.7	67.7	96.6	105.8	98.4	61.0	88.9	68.0
w/ SNI fuel	473.9	63.2	199.9	86.1	243.0	76.0	316.3	66.1	308.3	72.9

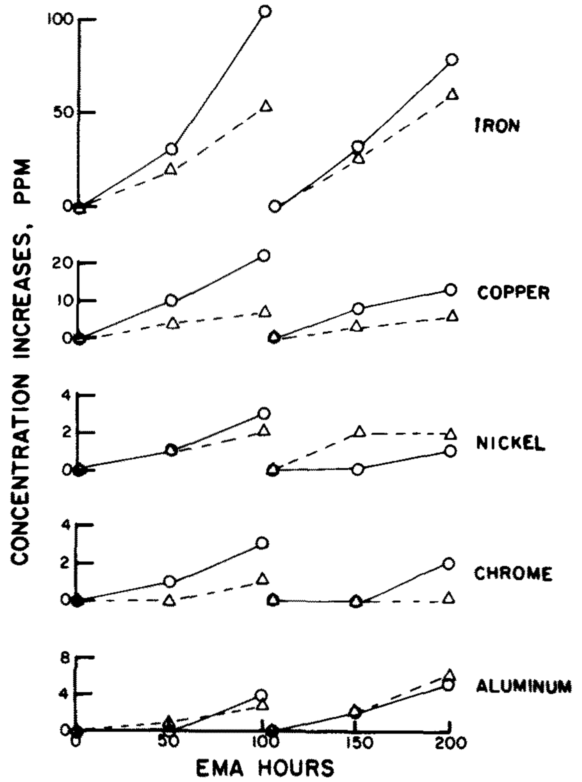

FIG. 3. Increases in wear metal concentrations in the engine oil. O–O diesel fuel; Δ- -Δ SNI fuel.

differences are apparent in the data. For main bearings, the cap inserts were more heavily loaded than the block inserts and the cap inserts showed greater weight loss. For rod bearings, the rod inserts had greater load and greater weight loss than the cap inserts. Surprisingly, the engine run on SNI fuel showed less wear in the bearings than the engine run on D2 fuel. Wear did not appear excessive on any of the bearings.

Micrometer measurements of valve stem and guide diameters were inconclusive. The micrometers could only be read to the nearest 0.025 mm (0.001 in.) and were not precise enough to detect wear to stem and guide with confidence.

From visual inspection, the type of fuel appeared to have no effect on wear on the liner. All liners exhibited light polish tracks in the ring travel area on both the thrust and antithrust sides. In the skirt travel area, all liners exhibited light polishing on the thrust side only. The type of fuel also had little effect on ring wear, as shown in Table IX.

Figure 3 shows increases in wear metal concentrations in the lubricating oil. Table X summarizes the possible sources of the wear metals. The engine running on SNI fuel showed less increases in most wear metals in the engine oil than the engine running on D2 fuel.

Carbon and Lacquer Deposits

In general, carbon deposits were heavier in Engine B (which ran on SNI fuel) than in Engine A (which ran on D2 fuel). In the combustion areas of the cylinder head, carbon deposits were similar on both engines. On the liners above the ring travel area, a partial carbon coating occurred in Engine A but a heavier, continuous coating occurred in Engine B.

More carbon was found on the intake valves than on the exhaust valves (see Table XI) in both engines. Flaky carbon deposits were found on the intake valve tulips. The flaky carbon deposits were much heavier in Engine B, which ran on SNI fuel. All intake valve stems were clean in the guide travel area in both engines.

All exhaust valves in both engines had light carbon deposits on the tulip and stem below the guide travel area. In Engine A, all exhaust valve stems were clean in the guide travel area. In Engine B, however, varnish deposits on the exhaust valve stems extended all the way to the top of the guide travel area. On cylinders 2 and 3, polished carbon deposits occurred on the exhaust valve stems in the guide travel area. On the top of the head of Engine B, a dome of carbon was found on the top of the exhaust valve guides, but the tops of the intake valve guides were clean. Carbon was apparently transferred through the exhaust valve guides on Engine B to form the domes at the top of the guides.

Carbon and lacquer deposits on the pistons were rated by Lubrizol corporation and the rating sheets are shown in Table XII. The overall demerit ratings were 351 for Engine A and 418 for Engine B. The deposits tended to shift lower on the pistons and were somewhat heavier in the engine running on SNI fuel. However, the average total groove fills did not differ significantly between engines and the deposit levels were not high enough to cause concern. Carbon on the top ring of Engine B was much harder and more difficult to remove than on Engine A.

Other Observations

At starting time each morning the temperature in the test cell was essentially equal to the outdoor temperature. An ether starting assist was needed to start either engine when temperatures were low. The engines were able to start immediately on either D2 or SNI fuel after initial warmup.

Engine B was subjected to ca. 20 hr of running without

TABLE XII

Ratings of Carbon Deposits on Pistons by CRC Method

Piston	Deposit Location Factor	Diesel Fuel TGF	Diesel Fuel WTD	SNI Fuel TGF	SNI Fuel WTD
1	Without	45	83	43	102
	With		288		440
2	Without	50	89	55	108
	With		311		410
3	Without	60	114	61	114
	With		443		422
4	Without	60	102	36	94
	With		363		400
Average	Without	54	97	49	104
	With		351		418
Average Crownland		64% Carbon		89% Carbon	
Average Under Crown		50% AL 38% LAL 10% VLAL		100%LAL	
Ring Face Wear Pattern		Good		Good	

TGF = Top Groove Fill; WTD = Weighted Total Deposit; With includes weighting of deposits by location, i.e., deposits on lower piston bands and in grooves are weighted heavier than those above; AL = Amber Lacquer; LAL = Light Amber Lacquer; VLAL = Very Light Amber Laquer; Data by Lubrizol Corporation, Wickliffe, Ohio.

TABLE XIII

Comparison of Engines

	AC 4331	Deere 4219D
No. of cylinders	4	4
Displacement, L	3.28	3.59
Compression ratio	14.5:1	16.3:1
Injector pump	Distributor-type	Distributor-type
Injector nozzles	regular, 4-hole	pencil-type, 4-hole
Orifice diameter, m	320	280
Rated speed, rev/min	2300	2200
BMEP at rated torque, kPa	1196	634
Fueling rate at rated power, kg/hr	19.3	12.7
Fuel per injection, mg/inj	280	192

TABLE XIV

Comparison of Fuels

	SF Blend	SNI
Type of vegetable oil	Sunflower	Soybean
Polar unsaturates in veg. oil, %*	74	62
Concentration of veg. oil, %v	25	25
Concentration of No. 2 diesel, %v	75	50
Concentration of alcohols, %v	0	25
Fuel viscosity @ 37.8 C, mm^2/s	4.50**	4.03
Cetane No.	44.0**	34.7

*Data from reference (8).
**Estimated.

load at various speeds while problems with the speed measurement system were being solved. During this time, fuel was observed to be slobbering from the turbine side of the turbochanger. The slobbering disappeared when the engine was started into the EMA test sequence and was operated under load most of the time.

DISCUSSION

The SNI fuel must be judged against the criteria established by the EMA. Engine B completed the 200-hr test sequence without changing injector nozzles or other parts. The lubricating oil survived the 100-hr change intervals without significant increases in viscosity. The rings did not stick during the tests, so blow-by was not excessive. Engine wear was comparable and in some cases less than with the D2 baseline fuel. In all of the above respects, the SNI fuel passed the tests for acceptance. However, the SNI fuel was close to the failure point in two respects.

Carbon deposits was heavier in the engine run on SNI fuel. Deposits forming on the injector nozzles were sufficient to begin interfering with the spray patterns, and carbon buildup also occurred in the valve guide areas of the exhaust valve stems. The power decreased ca. 5% in the final performance test. Apparently, the fuel was just on the borderline of failing the test. The engine may have possibly experienced difficulty with excessive carbon, especially on the injector tips, with continued running.

North Dakota State University and Allis Chalmers Company cooperated in EMA durability screening of a blend of 25% once-refined sunflower oil with 75% No. 2 diesel fuel (6). The blend did not pass the EMA criteria. The injection nozzles had to be changed twice during the 200-hr test because of excessive nozzle coking. Similarity of the blend and the SNI fuel (both contained 25% of once-refined vegetable oil) invites speculation as to why the former failed and the latter marginally passed the EMA screening criteria.

The blend was tested in an AC 4331 turbocharged, direct-injection diesel engine. Characteristics of the AC 4331 and Deere 4219D engines are listed in Table XIII for ease of comparison. The engines were similar in size and similarly equipped. However, the AC engine was fueled at a much higher rate and thus operated with much higher BMEP. It is unlikely that the higher BMEP caused the severe nozzle coking in the AC engine, but the presence of much greater amounts of fuel per injection could be a contributing factor. The injector nozzles also differed in design. The slender, pencil-type injectors in the Deere engine would receive less heat from the combusting gases and therefore probably ran cooler. Van der Walt and Hugo (7) found that cooler injection tips were less susceptible to coking.

Characteristics of the sunflower oil-diesel blend and the SNI fuel are shown in Table XIV for comparison. Because of its higher cetane rating and associated shorter ignition delay, the blend would undergo less premixed burning and more diffusion burning than the SNI fuel (9). Also, the higher viscosity of the blend would lead to poorer fuel atomization. However, that these differences could account for the more severe nozzle coking in the AC engine is doubtful. Chemical differences between fuels were more likely causes of differences in nozzle coking. The sunflower oil is higher in polyunsaturates than soybean oil, and Quick et al. (10) observed a strong correlation between polyunsaturation and injector fouling. Also, the 25% alcohol in the SNI fuel may have helped to keep the injectors clean. In a subsequent test, the AC engine was able to complete 257 hr of running on a microemulsion of sunflower oil, ethanol and butanol without changing injectors (11). The estimated viscosity of the microemulsion at 37.8 C was $6.77\ mm^2/s$, thus atomization would be expected to be poorer than with the sunflower oil-diesel blend. This result implies that the alcohols were beneficial in reducing nozzle coking. Two mechanisms are proposed for the beneficial in reducing nozzle coking. Two mechanisms are proposed for the beneficial effects of the alcohol. First, alcohols are excellent solvents and may have helped to keep the injector needles and orifices clean. Also, alcohols have high latent heat of vaporization and thus tend to cool the combustion chamber. As previsously mentioned, Van der Walt and Hugo (7) found that cooler injection tips are less likely to foul.

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Methyl and Ethyl Soybean Esters as Renewable Fuels for Diesel Engines[1]

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ABSTRACT

The primary problems associated with using straight soybean oil as a fuel in a compression ignition internal combustion engine are caused by high fuel viscosity. Transesterification of soybean oil with an alcohol provides a significant reduction in viscosity, thereby enhancing the physical properties of the renewable fuel to improve engine performance. The ethyl and methyl esters of soybean oil with commercial diesel fuel additives revealed fuel properties that compared very well with diesel fuel, with the exception of gum formation, which manifested itself in problems with the plugging of fuel filters. Engine performance using soybean ester fuels differed little from engine performance with diesel fuel. A slight power loss combined with an increase in fuel consumption were experienced with the esters, primarily because of the lower heating value of the esters than for diesel fuel. Emissions for the 2 fuels were similar, with nitrous oxide emissions higher for the esters. Measurements of engine wear and fuel-injection system tests showed no abnormal characteristics for any of the fuels after the 200-hr tests. Engine deposits were comparable in amount, but slightly different in color and texture, with the methyl ester engine experiencing greater carbon and varnish deposits on the pistons.

INTRODUCTION

Modern, mechanized food production systems are particularly sensitive to energy shortages, as was demonstated in the early 1970's. Petroleum prices rose dramatically, increasing the farmer's cost of production because of diesel fuel and through nitrogen fertilizer and pesticides derived from fossil fuel. Stringent conservation practices eased the burden somewhat, but the fact remains that petroleum is not a renewable resource and recent predictions (1) are that world oil production could start to decline in the 1990's.

Research and engine testing on the use of vegetable oils date back to the 1930's. Most of the data reflects the findings that these oils are practical for use in diesel engines. Problems were encountered because of excessive carbon deposits and thickening of lubricating oil. The high viscosity of the vegetable oils was largely responsible for these problems. The availability of low cost petroleum meant that little was done to solve these difficulties.

Recently, renewed interest in vegetable oils led to the testing of sunflower-oil esters by Bruwer (2) as a fuel for diesel engines. The ester form of sunflower oil has fuel properties that compare far better with diesel fuel than does neat sunflower oil. The engine test results were very encouraging. Dynamometer tests revealed that after 100 hr of operation at 80% of maximum power, the ester fuels actually caused less injector tip fouling than diesel fuel and yielded higher brake thermal efficiencies and lower smoke values.

In light of the promising results obtained with sunflower-oil esters, a suitable basis existed for comprehensive tests involving soybean-oil esters. Soybean oil was chosen because it is a renewable resource with well established crop production practices. The oil extraction process itself yields a valuable, high-protein oilcake as the major product. Soybean plants also supply most of their own nitrogen through nitrogen fixation, reducing fertilizer energy inputs and contributing to a positive energy balance in producing soybean oil (3). Soybean oil esters exhibit fuel properties similar to diesel fuel.

The objectives of this investigation were (a) to determine how the physical properties of ethyl and methyl esters of soybean oil compare with a standard diesel fuel and (b) to perform prescribed medium-term tests on a direct injection, turbocharged diesel engine to determine how engine wear, oil deterioration, exhaust emissions and engine performance for a soybean oil ester-fueled engine compare with a standard diesel fueled engine.

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