Laboratory Endurance Test of a Sunflower Oil Blend in a Diesel Engine

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ABSTRACT

The effects of using a 25/75 blend (v/v) of alkali refined sunflower oil and diesel fuel in a direct-injection diesel engine were compared to a baseline test with diesel fuel. There were no significant problems with engine operation during the baseline test. However, problems were experienced while using the blended fuel. The major problems were (a) abnormal buildup on the injection nozzle-tips, (b) injector needle sticking, (c) secondary injection, (d) carbon buildup in the intake ports, (e) carbon deposits on the exhaust valve stems, (f) carbon filling of the compression ring grooves, and (g) abnormal lacquer and varnish buildup on the third piston land. The 25/75 blend cannot be recommended for long-term use in a direct-injection engine.

INTRODUCTION

Many researchers of vegetable oil fuels have found that the relatively poor thermal stability of vegetable oil leads to a buildup of deposits in the combustion chamber, especially injector nozzle choking. The resultant degradation of fuel atomization and combustion efficiency leads to further problems such as piston ring sticking, crankcase oil dilution, and gelation of the lubricating oil resulting in engine failure (1-11). However, it has been hard to compare these research results, since they have all used different test cycles. In an attempt to standardize testing, the Alternate Fuels Committee of the Engine Manufacturers Association (EMA) has recommended a test cycle to be used for testing vegetable oil fuels (12). Some tests have been performed using this test cycle (13-15). This paper uses the EMA test cycle to compare the results of using a 25/75 blend (v/v) of alkali refined sunflower oil and diesel fuel in a direct-injection diesel engine to the results of a baseline test with diesel fuel.

FUEL PROPERTIES AND CHARACTERISTICS

The fuels utilized in these tests were D-2 diesel control fuel (Phillips Reference Fuel) and a 25/75 blend (v/v) of alkali refined sunflower oil and D-2 diesel control fuel. Fuels were obtained from commerical sources. No additives were used. All fuels were filtered through a 5-micron filter. Samples of the test fuels were analyzed using American Society of Testing and Materials (ASTM) standard procedures. Test fuel properties are in Tables I and II.

TABLE I

Diesel Control Fuel Properties

Cetane number	46.3
Distillation range	
IBP (C)	200
10% point (C)	224
50% point (C)	257
90% point (C)	296
End point (C)	323
Gravity, API	35.7
Sulfur (%)	0.25
Hydrocarbon composition aromatics (%)	29.8
Flash point (C)	75
Viscosity @ 40 C (mm^2/s)	2.44

TABLE II

Sunflower Oil Properties

Specific gravity		0.9174
Viscosity @ 38 C (mm^2/s)		33.9
Flash point (C)		274
Peroxide value (meq/1000 g)		14
Acid value (mg/g)		0.1
Iodine value (cg/g)		130
Moisture (%)		0.03
Phosphatide content (%)		0.01
Fatty acid distribution (%)		
Palmitic	16:0	6.0
Stearic	18:0	4.2
Oleic	18:1	18.7
Linoleic	18:2	69.3
Linolenic	18:3	0.3
Arachidic	20:0	0.4
Eicosenoic	20:1	0.1
Behenic	22:0	1.0

APPARATUS AND PROCEDURE

These tests were conducted at the Allis-Chalmers Engine Division in Harvey, IL. A direct-injection, intercooled and turbocharged, four-cylinder Allis-Chalmers diesel engine, model 433I, was selected because of its typical current design, relatively small size, and low fuel consumption. The displacement of this engine is 3.28 L with a 9.84 cm bore and 10.80 cm stroke. It has 14.5:1 compression ratio. A Stanadyne Roosa Master Distributor Pump Type DB2 was used with two 9.40 mm pumping plugers. The injection nozzle used was a Robert Bosch nozzle with four 0.32 mm diameter orifices, a 1.1 mm sac length, and a 1.0 mm sac diameter. Prior to the test run, the engine was completely disassembled, all critical parts were measured, and the engine was rebuilt in strict accordance with all furnished specifications. Following this preparation, the engine was installed on a dynamometer test stand equipped with appropriate accessories for controlling speed, load and other engine operating conditions. The engine was operated on a cycle recommended by the Alternate Fuels Committee of the Engine Manufacturer's Association (EMA). The EMA cycle for the AC 433I engine is presented in Table III. The cycle was repeated five times (15 hr). Average cycle power was maintained at ca. 70%. After 15 hr on the cycle, the engine was shut down for 9 hr. This procedure was repeated until 200 hr of operation on the test cycle had been completed. At the conclusion of the test, the engine

TABLE III

EMA Test Cycle for AC 433I Engine

Step	Speed (rpm)	Torque (kNm)	Brake mean effective pressure (kPa)	Time (min)
1	2300	3.36	1196	60
2	1955	3.72	1327	60
3	2070	0.93	333	30
4	750	0	0	30
				180

was disassembled, visually inspected, measured, and rated to determine the extent of varnish and carbon formation.

Fuel consumption was measured on a weight basis with a Cox Instrument Fuel Consumption Weight System, Type 402. A Robert Bosch (RB) Model EFAW 68A smokemeter was used to analyze exhaust smoke. Three samples were taken and the average reading was recorded. The dynamometer used to load the engine was a Dynamic Asorbing Dynamometer, Model 1014 D.G. Fuel injection line pressures were measured at the nozzle with a Kistler Model No. 607F122 piezoelectric pressure transducer. The pressure output signals were conditioned with a charge amplifier. A magnetic inductance sensor manufactured by DALEC, Data Electronics Corporation, sensed the location of a top dead center (TDC) indicator affixed to the flywheel. Outputs from the pressure transducer and magnetic sensor were displayed on a Nicolet Instrument Corporation Explorer III digital oscilloscope and stored in a Tektronix 4052 Graphic Computer System. Fifteen randomly selected line pressure traces were collected for each cylinder every 50 test cycle hours. The data was taken for all four cylinders at rated load (2300 rpm) and at peak torque (1800 rpm). Additionally, pressure traces for cylinder 4 were taken at high (2530 rpm) and low idle (750 rpm).

RESULTS

General Test Observations

Although the EMA recommended 200 hr of operation on their test cycle, the engine logged more total hours of operation because of time needed to take performance data and pressure readings throughout the test. The engine operated for 321 total hours while using diesel fuel, and for 268 total hours while using the 25%75 blend. The engine running on diesel control fuel completed the test without requiring a fuel filter change. During 321 hr of engine operation the pressure before the fuel injection pump was maintained between 20 and 28 kPa according to the manufacturer's specification. A fuel filter change was necessary while operating on the 25/75 blend after 100 hr of testing.

Engine Performance Results

Figure 1 shows engine output and operating conditions recorded at the beginning and end of the test on diesel control fuel. The power output during the 200-hr test did not show any deterioration. The decrease in peak power at 2200 rpm after testing was insignificant (1.1%). Brake specific fuel consumption (BSFC) showed slight regression in conjunction with increased time of engine operation. The change observed at peak torque (1.5%) was similar at 2000 rpm (1.7%). Higher speed provided somewhat improved BSFC and at 2300 rpm it was 0.5% lower than at the beginning of the test. Both the loss and gain in BSFC were relatively modest in absolute value. The variation in RB smoke level appears to be consistent with the variation in BSFC. The increase in exhaust temperature was caused by higher air intake temperature and by slightly lower combustion efficiency. The gain was insignificant.

Figure 2 compares initial engine performance and operating conditions for diesel fuel and the 25/75 blend test. Engine power output over the tested engine speed range was slightly higher for the 25/75 mixture. At rated speed (2300 rpm) the difference was 2.5%. At 1800 rpm the gain in power was 6%. The tendency toward larger differences in power output at lower engine speed was possibly caused by increasing time available for combustion, which appears beneficial for the 25/75 mixture. The RB smoke level of the 25/75 blend, compared to diesel fuel,

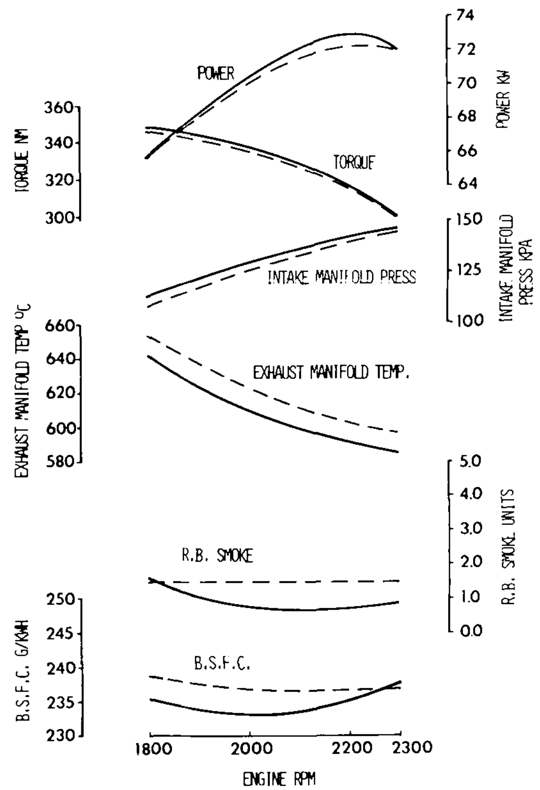

FIG. 1. Engine performance at beginning and end of EMA test cycle while using diesel fuel. ——— Beginning of test; – – – – – end of test.

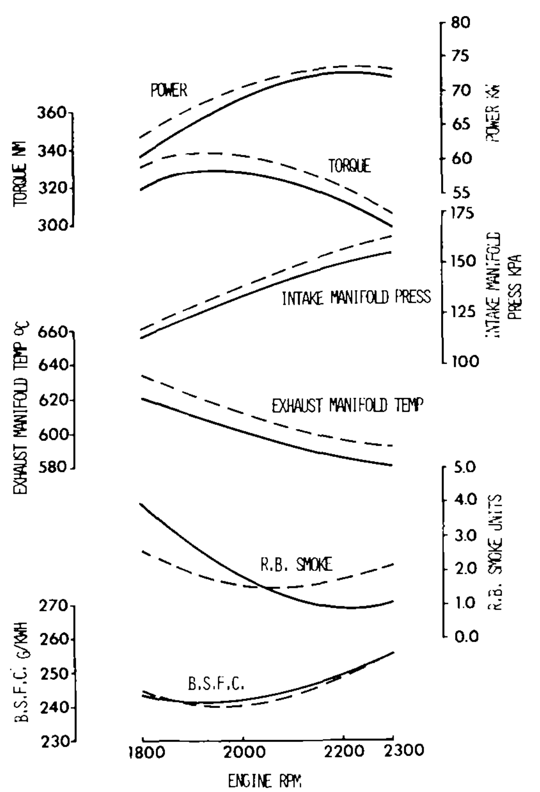

FIG. 2. Comparative engine performance between diesel fuel and a 25/75 SFO-2D blend. ——— Diesel fuel. – – – – – 25/75 SFO-2D blend.

increased at higher engine speed (from 1.0 to 2.2) and decreased at lower engine speed (from 4.0 to 2.6). BSFC was similar for the tested fuels. However, the differences in energy content per unit of mass between the 25/75 blend and diesel fuel would cause the brake specific energy consumption for the 25/75 blend to be lower than for diesel fuel. Greater exhaust temperature for the 25/75 blend was caused by higher intake air temperature during the test. Higher exhaust temperature caused the turbocharger to run faster and produce greater intake manifold pressure.

Figure 3 shows engine performance and operating conditions recorded at the beginning and end of the 25/75 blend test. The power output after 200 hr of the test (163 hr on the fuel injection nozzles) did not show a significant change, with the exception of a 2.5% loss at 2300 rpm. This could indicate the beginning of injection nozzle deterioration. After 200 hr, the BSFC was unexpectedly lower. This may have been caused by some polymerized sunflower oil residue remaining on the fuel scale. The RB smoke level was higher after the test. At 2300 rpm the smoke level increased from 2.2 to 3.5 RB smoke units and at 1800 rpm from 2.6 to 3.1 RB smoke units. The exhaust temperature increased but not significantly.

Statistical analysis of engine performance. A linear regression analysis was used to test for a significant relationship between the engine performance variables (power, BSFC and exhaust temperature) and hours of engine operation.

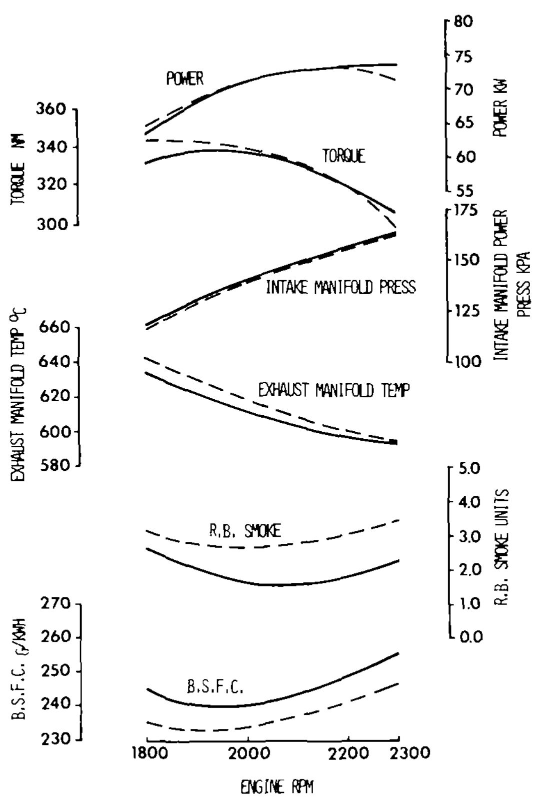

FIG. 3. Engine performance at beginning and end of EMA test cycle while using a 25/75 SOF-2D blend. ——— Beginning of test; – – – end of test.

For all tested parameters, the hypothesis of dependence was rejected at the 5% level of significance. The standard errors for the test variables indicated a greater standard deviation of the dependent variables for hours of engine operation on the 25/75 mixture compared to diesel fuel.

Injection System

Injection nozzles. One set of the injection nozzles was used during 321 hr of engine operation on diesel fuel. After the test, all tips showed normal carbon residue. The highest nozzel opening pressure drop was ca. 10% for nozzle 3. The lowest nozzle opening pressure drop was ca. 8% for nozzles 1 and 2. Inspection showed that a reduction in orifice diameters for nozzles 2 and 3 only. Following the diesel test, no leak was observed for all nozzles when tested on the injection nozzle test stand.

During 268 hr of engine operation with the blended fuel, the injection nozzles were changed twice. The first set of nozzles were changed at 29 hr of engine operation. The change was made because of problems with the fuel injection pump which may have resulted in injector coking not caused by the test fuel. The second change was made after 105 hr of engine operation (76 hr of operating with the injectors) when a drop in power and significant differences in fuel injection line pressures for cylinders 2 and 3 were experienced. The power output dropped at 2300 rpm from 77.6 kW to 73.4 kW. The BSFC was slightly elevated. The smoke level was unexpectedly low (0.5 RB smoke units). All tips showed abnormal carbon residue. The highest nozzle opening pressure drop was ca. 18% for nozzles 2 and 4. The remaining two nozzles had a 13% drop in nozzle opening pressure. Inspection showed a reduction in orifice diameter for all tested nozzles. Scuffing was observed on the needles from nozzles 2 and 3. This suggests a reduction in the needle-to-housing clearance and difficulty in needle movement. During the injection nozzle stand test no leak was observed for all nozzles. The third set of nozzles performed 163 hr. All tips also showed an abnormal buildup of carbon. The nozzle opening pressure drop was 7% and was uniform for all nozzles. Inspection showed a reduction in orifice diameter for all nozzles. For nozzles 2 and 4 a uniform reduction was observed. Nozzle 1 had one plugged orifice. The second set of nozzle needles did not show excessive wear. During the injection nozzle stand test, no leak was observed for all nozzles.

Injection line pressure. Injection line pressure analysis during the 25/75 blend test indicated erratic deterioration of the injection system. During the test sporadic nozzle needle sticking, needle reopening, and secondary injection was experienced. A drop in amplitude of the residual line pressure due to needle sticking and/or poor needle seating with consequent fuel dribble was recognized (Figs. 4a and 4b). For nozzle 4 after 105 hr of operation, the residual line pressure dropped at 2300 rpm from 5.9 MPa to 4.1 MPa (point A, Figs. 4a and 4b) and at 1800 rpm from 5.5 MPa to 1.4 MPa. The maximum residual line pressure decreased 2300 rpm from 20.0 MPa to 13.8 MPa (point C, Figs. 4a and 4b) and at 1800 rpm from 17.9 MPa to 11.0 MPa. Needle reopening and secondary injection for nozzle 1 was apparent after 163 hr of operation (Figs. 4c and 4d). Reduction in orifice diameters for nozzle 1 due to carbon deposits was significant. One orifice was plugged, two orifices showed a reduction in diameter from 0.32 mm to 0.305 mm, the fourth orifice decreased from 0.32 mm to 0.31 mm. This translated to a total nozzle orifice area reduction of ca. 30% which increased the maximum injection line pressure, (point B, Figs. 4c and 4d), the residual injection line pressure (point A, Figs. 4c and 4d) and maxi-

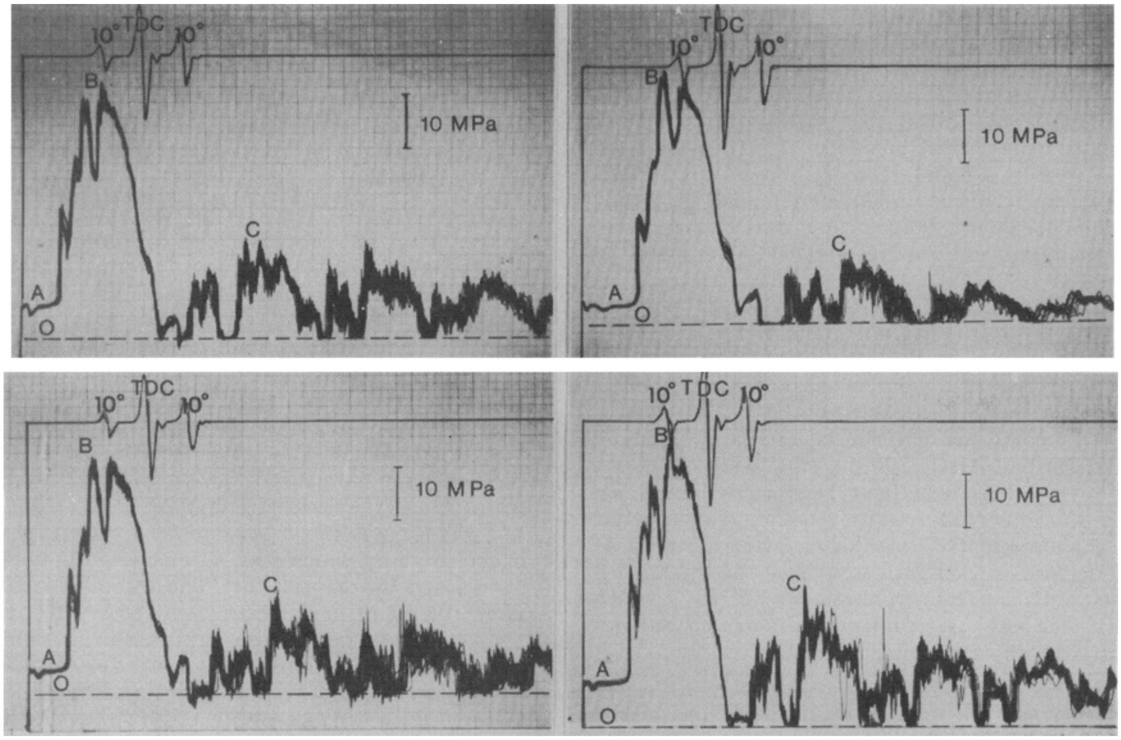

FIG. 4. Timing marks and injection pressures for 15 observations at rated speed and load. (a) Nozzle 4 – new, (b) nozzle 4 – 105 hr of use, (c) nozzle 1 – new, (d) nozzle 1 – 163 hr of use. _____ Baseline pressure (fuel vapor pressure). (A) Residual line pressure, (B) maximum line pressure, (C) maximum residual line pressure.

mum residual injection line pressure (point C, Figs. 4c and 4d). For this nozzle, the maximum injection line pressure increased from 50.3 MPa initially to 62.1 MPa after 163 hr of engine operation. Similarly, the residual injection line pressure increased from 5.5 MPa to 9.0 MPa and the maximum residual injection line pressure increased from 21.4 MPa to 29.7 MPa. The injector had an opening pressure of 27.0 MPa initially which decreased to 25.1 MPa after 163 hr of engine operation. Hence, when the injector became coked, the maximum residual line pressure was greater than the nozzle opening pressure and secondary injection occurred.

Lubricating Oil

During the D-2 diesel fuel test, the lubricating oil consumption was 16.04 g/hr (Fig. 5a). On the 25/75 blend, the lubricating oil consumption from 0 to 105 hr of engine operation was very low (11.61 g/hr). Between 105 and 150 hr, the oil consumption was 78 g/hr, even though no outside leaks were observed. The average oil consumption for the whole test was 16.11 g/hr (Fig. 5b). For both tests the blowby stayed at a satisfactory level. The blowby for the diesel fuel test was 92 L/min (Fig. 5a). The blowby for the 25/75 blend test was 90 L/min (Fig. 5b).

Oil samples taken every 15 hr were used to determine the change in kinematic viscosity and dispersivity characteristics. The lubricant viscosity measured at 40 C was within normal limits during both tests (Fig. 6). For both tested fuels, analysis of "blotter spot" samples did not indicate abnormal changes in lubricant dispersivity characteristics during the tests.

Engine Teardown and Final Inspection

After each durability test, the carbon, sludge and varnish deposits were rated using the Coordinating Research Council (CRC) test procedure (16). The wear of engine parts was determined by direct measurement.

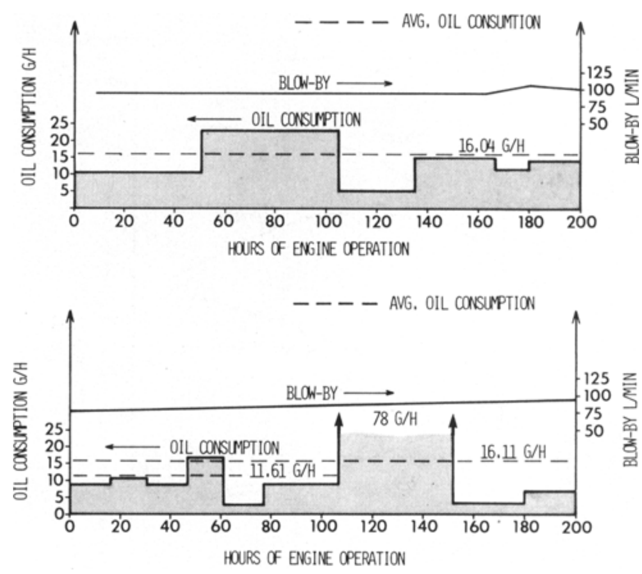

FIG. 5. Oil consumption and blowby, (a) diesel fuel, (b) 25/75 SFO-2D blend. _____ Average oil consumption.

Cylinder head, intake and exhaust values. For both tested fuels the combustion area of the cylinder head showed light, uniform, flat carbon buildup. The manifold and combustion side of the exhaust port as well as the manifold side of the intake port appeared clean. The combustion side of the intake port showed soft, oily, uniform carbon buildup. For the engine tested on the 25/75 blend, heavy carbon residue was visible underneath the valve seat. The average CRC rating for the intake passage surface was 1.6 for the 25/75 blend test and 1.13 for the diesel fuel test.

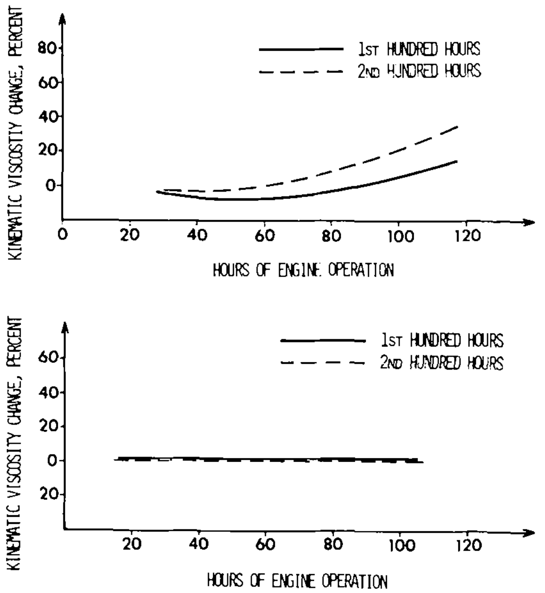

FIG. 6. Kinematic viscosity change, (a) diesel fuel, (b) 25/75 SFO-2D blend. ——— 1st hundred hours; – – – – 2nd hundred hours.

No difference in carbon buildup on the intake and exhaust valve tulips was detected for the tested fuels. However, for all exhaust valves after the 25/75 blend test, the valve stems displayed excessive carbon residue (Fig. 7). The average CRC rating for exhaust stem deposits was 1.9 for the 25/75 blend test and 0.8 for the diesel fuel test. For both tests all valve faces showed light peening caused by hard particles of combustion chamber deposits.

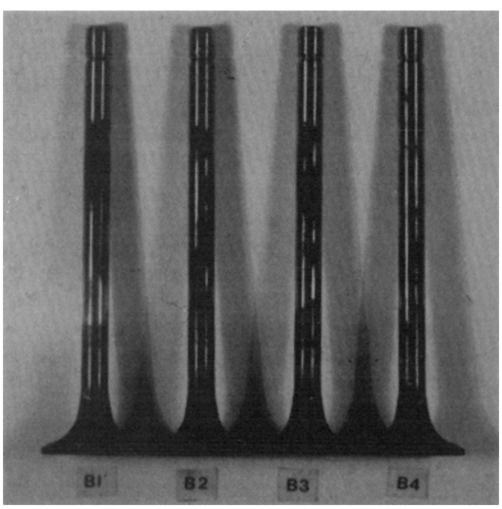

FIG. 7. Exhaust valve stem deposist after durability test with 25/75 blend.

Cylinder sleeves. Heavy and hard carbon residue was observed on the cylinder sleeevcs above the ring travel after the 200-hr test with the 25/75 blend. The cylinder sleeves had some scratches throughout the inside surfaces on the major and minor thrust side. For all sleeves the scratches were only superficial. This was apparent under high magnification which showed the original hone marks to be deeper than the scratches. The scratching was caused by the piston rather than the rings because the scratches extended below the lowest level of ring travel and metal was smeared on the sides of the piston. Overall, the cylinder sleeves were in very good condition and showed fewer scratches than when the engine was run on diesel fuel. The average CRC rating for carbon deposits above the top ring was 1.1 for the diesel fuel test, compared to 1.22 for the test on the 25/75 blend.

Piston and rings. Pistons for both tests showed heavy carbon buildup right above the ring groove on the top land and normal carbon residue on the second land. For the pistons after the 25/75 blend test, the lacquer and carbon residue on the third land was significantly heavier than after the diesel fuel test. All deposits from the test on the 25/75 blend were hard, shiny, and did not flake off as was found with the dry carbon buildup formed during the run on diesel fuel.

Inspection, showed differences in volume of ring groove filling with carbon. After the 25/75 blend test, the piston grooves for all compression rings were filled with carbon. The deposits were greater than those seen on the diesel fuel test (Table IV).

Piston ring side clearance was measured right after the test with the carbon buildup in place and remeasured after cleaning. For the diesel test, the top side of the first groove appeared clean, and 44% of the second groove top side was covered by light carbon buildup. On the 25/75 blend, 20% of the top side had carbon residue, and 78% of the second groove top side area appeared black.

Inspection of the piston combustion chamber after the test on 25/75 blend revealed evidence of a denser fuel spray core for three cylinders (Fig. 8). Carbon buildup on the piston chamber wall corresponding to the points of fuel impact from a multihole nozzle was not uniform. The impingement points were surrounded by a larger area where the fuel vapor or fuel flame was reflected from the combustion chamber wall. The appearance and location of the impingement area varied and corresponded to a relative reduction of nozzle orifice diameters. For cylinder 4, no reduction of the nozzle orifice diameters and corresponding increase in injection line pressure was experienced. Regular, light impingement marks were apparent on the piston combustion chamber of cylinder 4 (Fig. 9).

After the diesel fuel test, the orifice diameters of two injection nozzles were reduced. Visible on the piston head were impingement marks surrounded by carbon buildup and a larger area of fuel vapor or fuel flame reflection (Fig. 10). The form of the carbon buildup, fuel, vapor and flame impingement areas were smaller and more uniform for the diesel test as compared to the 25/75 blend test.

Bearings. For both tests the rod and main bearings were in good condition. No deposits were visible. All bearings showed a normal wear pattern.

Turbocharger. At the conclusion of both tests the turbochargers were in satisfactory condition. The turbine wheels were covered with normal light carbon residue. For the turbocharger tested on the 25/75 blend the carbon buildup had a sticky and oily appearance.

Engine measurements. Compared to initial measurements, the final results did not indicate significant engine parts wear.

DISCUSSION

A linear regression analysis was used to test for degradation of engine performance parameters (power, BSFC, exhaust temperature, etc.) with test cycle time. The hypotheses of dependence was rejected at the 5% level of significance for all parameters of both tests indicating no change in performance. The standard errors of the test variables

TABLE IV

Piston Deposit Ratings

	D-2 Diesel control fuel							
	1st ring		2nd ring		3rd ring		oil ring	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Ring groove filling (% vol)	83	13.02	36	7.61	0	0	0	0
Carbon buildup on side of ring groove								
top	0	0	0.60	0.14	0	0	0	0
bottom	0	0	0	0	0	0	0	0
Carbon buildup on ring								
top	0.17	0	0.51	0	0	0	0	0
bottom	0	0	0.53	0.61	0	0	0	0
back	1.05	0	1.05	0	0	0	0	0
front	0	0	0.30	0.08	0	0	0	0

	25/75 Blend							
	1st ring		2nd ring		3rd ring		oil ring	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Ring groove filling (% vol)	92	9.46	51	12.99	12	8.3	0	0
Carbon buildup on side of ring groove								
top	0.37	0.13	0.86	0.07	0	0	0	0
bottom	0	0	0	0	0	0	0	0
Carbon buildup on ring								
top	0.04	0.09	0.60	0.06	0	0	0	0
bottom	0	0	0	0	0	0	0	0
back	0.66	0.16	1.05	0	0	0	0	0
front	0	0	0.30	0.22	0	0	0	0

Ave. = average CRC diesel engine rating for four cylinders.
SD = standard deviation.

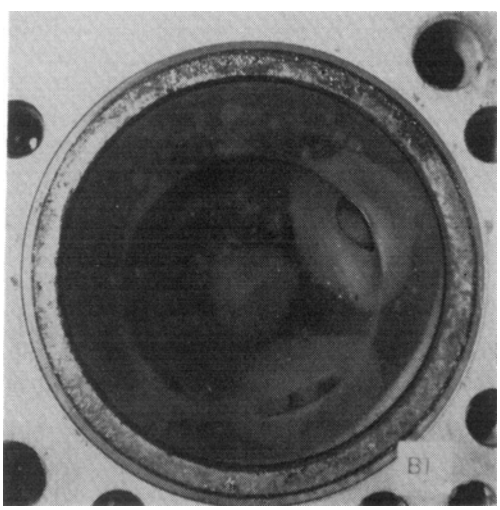

FIG. 8. Carbon buildup on piston 1 after durability test with 25/75 blend.

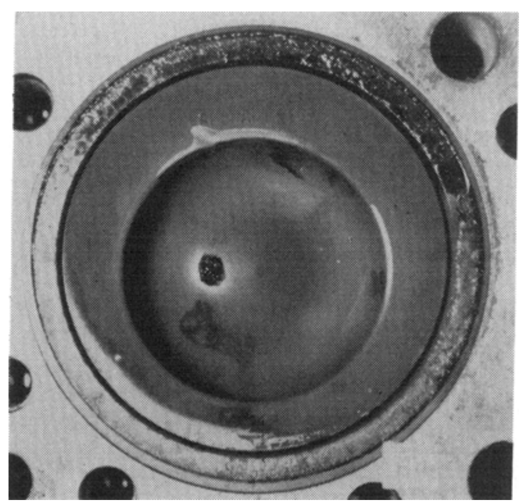

FIG. 9. Carbon buildup on piston 4 after durability test with 25/75 blend.

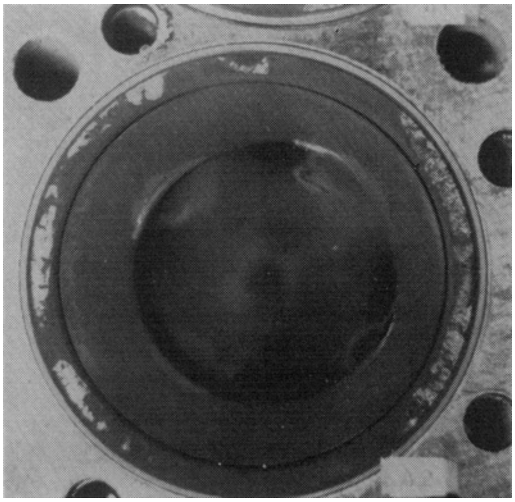

FIG. 10. Carbon buildup on piston 2 after durability test with diesel fuel.

indicated a greater standard deviation of the performance parameters for the 25/75 mixture compared to diesel fuel. This was possibly caused by erratic deterioration of the fuel injection system.

During the test on the 25/75 blend the injection nozzles were changed twice. The first change was made after 29 hr of engine operation due to injection pump problems. The second change was made after 105 hr of engine operation when a 5% drop in power and significant differences in fuel injection line pressures were experienced. With the 25/75 blend:

- All nozzle tips showed abnormal carbon buildup.
- The highest nozzel opening pressure drop was 18%.
- For all tested nozzles a reduction in orifice diameters was experienced.
- The needles showed lacquer buildup which caused difficulty in needle movement for two nozzles from the second set of nozzles.

Injection line pressure analysis indicated erratic deterioration of the fuel injection system, including sporadic nozzle needle sticking, needle reopening and secondary injection. The lubricating oil consumption for the 25/75 blend test was slightly less than the lubricating oil consumption for the run on diesel fuel. Blowby stayed at a satisfactory level for both tests. The lubricating oil kinematic viscosity did not change significantly for either test.

Comparing the engine condition after the 25/75 blend test to the diesel fuel test:

- There was a slightly heavier soft carbon buildup in the intake ports.
- All four exhaust valve stems had heavy black carbon deposits.
- The cylinder sleeves had a heavier carbon buildup above the ring travel but less polish tracks and scratches in the ring travel area.
- The pistons had more lacquer and carbon residue on the third land.
- The carbon deposits did not show a tendency to flake off.
- The piston grooves for all compression rings had heavier carbon buildup.
- There were no significant differences in engine parts wear.

Inspection of the piston combustion chamber after the test on both fuels revealed evidence of a dense fuel spray. The appearance and location of the impingement areas varied and corresponded to a relative reduction of nozzle orifice diameters. The impingement areas were smaller and more uniform for the diesel test compared to the 25/75 blend test.

Based on the results of these tests, the 25/75 blend could not be recommended for long-term use in a direct-injected diesel engine. Problems such as unexpectedly early deterioration of injection nozzle performance, piston ring groove carbon filling, heavy carbon on the piston lands, and heavy carbon buildup on the cylinder liners above the top of the ring travel were experienced. These problems would result in premature engine failure.

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REFERENCES

1. Bacon, D.M., F. Brear, I.D. Moncrieff and K.L. Walker, Beyond the Energy Crisis, Vol. III, edited by R.A. Fazzolare and C.B. Smith, Pergamon Press, 1981, p. 1525.
2. Barsic, N.J., and A.L. Humke, Paper no. 810262, Society of Automotive Engineers, Warrendale, PA, 1981.
3. Borgelt, S.C., and F.D. Harris, in Vegetable Oil Fuels, Proceedings of the International Conference on Plant and Vegetable Oil as Fuels, Fargo, ND, 1982. American Society of Agriculture Engineers Publication 4-82, ASAE, St. Joseph, MI, 1982, p. 364.
4. Bruwer, J.J., B.V.D. Boshoff, F.J.C. Hugo, J. Fuls, C. Hawkins, A.N.V.D. Walt, A. Engelbrecht and L.M. duPlessis, in Agricultural Energy, Vol. 2, American Society of Agricultural Engineers Publ. no. 4–81, ASAE, St. Jospeh, MI, 1981, p.385.
5. Cochran, B.J., J.D.C. Baldwin and L.R. Daniel, Jr., Ibid. p.391.
6. Engleman, H.W., D.A.Gunther and T.W. Silvis, Paper no. 78-DGP-19, American Society of Mechanical Engineers, New York, NY, 1978.
7. Johansson, R., and O. Nordstrom, in Vegetable Oil Fuels, Proceedings of the International Conference on Plant and Vegetable Oils as Fuels Fargo, ND, 1982. American Society of Agricultural Engineers Publication 4-82, ASAE, St. Joseph, MI, 1982, p. 337.
8. Quick, G.R., B.T. Wilson and P.J. Woodmore, Ibid. p. 239.
9. Strayer, R.C., W.K., Craig and G.C. Zoerb, Ibid. p. 347.
10. Wagner, G.L., and C.L. Peterson, Ibid. p. 329.
11. Ziejewski, M., and K.R. Kaufman, Paper no. 820257, Society of Automotive Engineers, Warrendale, PA, 1982.
12. 200-Hour Screening Test for Alternative Fuel, Northern Agricultural Energy Center Notes, Northern Regional Research Center, USDA Peoria, IL 1982.
13. Baranescu, R.A., and J.J. Lusco, Paper no. 820260, Society of Automotive Engineers, Warrendale, PA, 1982.
14. Fort, E.F., P.N. Blemberg, H.E. Staph and J.J. Staudt, Paper no. 820317, Society of Automotive Engineers, Warrendale, PA, 1982.
15. McCutchen, R., in Beyond the Energy Crisis, Vol. III, edited by R.A. Fazzolare and C.B. Smith, Pergamon Press, 1981, p. 1679.
16. Diesel Engine Rating Manual, Diesel Vehicle Fuel, Lubricant and Equipment Research Committee of the Coordinating Research Council, 1959.

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