LONG-RANGE ON-ROAD TEST WITH TWENTY-PERCENT RAPESEED BIODIESEL

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ABSTRACT. *A heavy-duty pickup truck with a 5.9-L diesel engine was targeted to operated on a blend of 20% methyl ester of rapeseed oil (RME) and 80% 2-D diesel (2-D) for 161 000 km (100,000 miles). The actual blend used was 27.9% RME. The engine was unmodified, but modifications were made to the vehicles for the convenience of the test. Fuel mixing was done on-board to extend the driving range to over 5000 km (3,100 miles) between biodiesel fill ups. Rusting of the mild steel fuel tanks contributed to fuel filter plugging which was eventually solved by changing to stainless steel tanks and switching to a different fuel supplier. Chassis dynamometer testing, injector coking, engine compression, injector valve opening pressures, and engine oil analyses were completed at regularly scheduled intervals to monitor the engine performance parameters. RME produced 5% less power than 2-D, while 20RME produced 1.5% less power than 2-D. Smoke density was reduced 32% with RME, while 20RME increased smoke density 6.6% higher than that of 2-D. The results of the oil analysis showed that there was no unusual deterioration of the engine, or any unusual change in oil composition from using the biodiesel fuel. Using aluminum and iron as comparison analysis, the test vehicle averaged 2.2 ppm for aluminum and 8.0 ppm for iron, the first check vehicle averaged 2.4 ppm for aluminum and 8.5 ppm for iron, the second check vehicle averaged 5.4 ppm for aluminum and 20.0 ppm for iron, and a third check vehicle averaged 5.7 ppm for aluminum and 64 ppm for iron (the third of four samples showed iron at 183 ppm with the others at 20-28 ppm.) Engine compression and injector valve opening pressure remained constant throughout the test. Emissions tests with a chassis transient dynamometer at the Los Angeles Metropolitan Authority Emissions Test Facility resulted in a decrease in HC (20%), CO (25%), NOx (2.6%), PM (10.9%), and there was no difference in CO_2 with 20RME compared to 2-D. When the vehicle reached 163 800 km (101,785 miles) the diesel engine was removed from the truck and shipped to Cummins Engine Company in Columbus, Indiana, for analysis. The condition of the engine obviously reflected the light load condition used in the pickup. However, it was generally considered to be in a condition which could be characterized as good or better than that which would have been expected with diesel fuel. Engine parts were clean and showed little wear. Adverse effects were hardening of the crankshaft seals which made a slight depression where they made contact with the shaft; and rusting of the fuel filter attachment stud. The fuel pump, although showing varnish, was found to be in good condition in the bench test.*

Keywords. *Alternative fuels, Biodiesel, Liquid fuels, Rapeseed.*

During the past decade, the United States has become increasingly dependent upon imported oil to meet its energy demands. In 1989, approximately 2,940 million barrels of oil, nearly 45% of total U.S. consumption, were imported. Since the Persian Gulf Crisis, there has been heightened interest in development of alternative liquid transportation fuels. Research teams at several universities and the United States Department of Agriculture have shown that the American farmer can help reduce the United State's dependence on imported oil by using excess agricultural production to grow oil-seed fuels. Diversion of only 10% of the cropland to the production of oil-seed fuels could provide all the diesel fuel required for American agriculture. Diversion of approximately 25% of the cropland could produce 218 million barrels of oil which could provide a third of the United State's transportation diesel while reducing our foreign trade deficit by over $5 billion.

Alcohol ester of vegetable oil (biodiesel) fuels are produced by reacting the oil extracted from rapeseed, sunflowers, soybeans or other oil-seed crops with either methanol or ethanol and a catalyst. These alcohol esters can be substituted for diesel fuel in unmodified diesel engines without reducing either performance or expected engine life. Also, it has been shown in Europe that a blend of straight rapeseed oil and diesel can work in unmodified precombustion chamber diesel engines. Farm-grown fuels contain very low levels of both sulfur and aromatic compounds which help reduce emissions of SO_2 and volatile organic compounds. Also, biodiesel fuels or blends

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EPA certified laboratory. Carbon monoxide emissions were reduced by 1%, hydrocarbon emissions were reduced by 48%, and particulate matter emissions were increased by 13% when the engine was fueled with soydiesel.

Holmberg and Peeples (1994) summarized the work done for the National SoyDiesel Development Board. Biodiesel has accumulated nearly eight million miles in demonstrations involving more than 1,500 vehicles in fleets across the country, particularly in urban buses. Biodiesel has been used successfully as a motor fuel in many types of equipment from water craft to locomotives. The results of numerous studies and demonstrations show the performance of biodiesel to be substantially similar to, if not better than, diesel. They predicted that as a renewable fuel with a very positive energy balance, biodiesel would be a major contributor to the stabilization of greenhouse emissions. They also reported that by using state-of-the art engine technology, biodiesel reduced EPA-regulated emissions of PM, CO, THC, and NOx. Actual emissions tests do not verify their optimism that biodiesel will reduce both NOx and PM.

Pischinger et al. (1982) reports on tests with the Volkswagen 1.6-L diesel indirect injection engine installed in a VW Passat passenger car or a delivery van. In Volkswagen's rigid durability test program for diesel engines, the diesel engine was fueled with 100% methyl ester of soybean oil (MESO.) It was dynamometer tested for 1,418 h operating about 70% of the time at maximum power and 20% at maximum torque. Values of torque, power, smoke levels, and cylinder compression remained within the normal variations expected for this test. Engine wear of the bearings, piston rings, cylinder bores, and valve train remained within the VW specifications. Differences in emissions and fuel consumption of the Passat diesel when comparing diesel fuel and MESO fuel were measured on a chassis dynamometer. A city driving cycle and a warm engine were used in the test. They reported that CO was 40% less, NOx increased 2.7%, and fuel consumption was increased 6% compared to diesel fuel.

Mittelbach and Tritthart (1988) tested a Volkswagen diesel Rabbit powered by a 1.6-L, four cylinder, four-stroke, direct injection engine with a 50/50 volume blend of methyl ester of used frying oil and diesel fuel. A total of 100 L of ester fuel were consumed. They reported that "no changes in operation whatsoever could be observed. The smoke emissions were extremely low and only a faint smell of burnt fat was detected. No volumetric fuel consumption was observed. They reported that "in our test the fuel consumption was almost the same as when using diesel fuel." They stated, "about a 10% power loss with ester fuel can be expected with unchanged fuel delivery of the injection pump. However, because particulate emissions are halved when using ester fuel, a higher fuel input for the ester fuel may be tolerated by the engine without excessive full load smoke. So the engine power may become comparable for both fuels without any deteriorating effects on emissions." In their vehicle testing, they reported that a diesel Volkswagen Passat had run 26 500 km (16466), and a Volkswagen van 5200 km (3,231 miles) with MESO. It was difficult to identify any difference between the MESO-fueled vehicles compared to identical diesel-fueled vehicles.

Shafer (1994), from Mercedes-Benz Germany, reports on the use of methyl esters of soybean oil, rapeseed oil, and palm oil. The testing was performed in Germany and Malaysia in trucks, busses, and industrial engines. Shafer (1994) concludes that, if the fuel (RME and palm methyl ester [PME]) is of high quality, the fuel injection system can remain unchanged and no excess nozzle coking will be found. He found that a high glyceride content in the esters causes nozzle coking. In their studies, the black smoke emission was reduced by at least 50%. Also, the disagreeable odor was reduced by installing an oxidation catalyst. They also state that engine oil dilution is within relatively tight limits and that no sludge is apparent with a suitable lubricating oil.

Alfuso et al. (1993) reported on the characterization of the behavior of methyl ester of rapeseed oil in direct injection diesel engines at Istituto Motor of CNR. Regulated and unregulated emissions were monitored using transient and steady-state conditions with varied injection timing, with and without a catalytic convertor and exhaust gas recirculation (EGR). Tests indicated that RME promotes a rise in NOx emissions and a decrease in HC and CO, as well as a large reduction of smoke. Particulate matter produced by RME in transient cycles is higher than that obtained with 2-D. Using the EGR, in the presence of an exhaust-oxidating catalyst, showed a reduction in NOx, HC, and CO emissions and low effects on particulate matter with RME.

Numerous feedstocks for biodiesel exist, including rapeseed, tallow, soybean, canola, peanut, sunflower, cottonseed, safflower, coconut, palm, and used cooking oils with which methyl or ethyl esters may be produced. Biodiesel reduces the opacity of smoke by up to 80%, decreases power by 6%, and increases fuel consumption 4%, due to the heat content of biodiesel being about 11% less than 2-D. It also decreases HC by as much as 50%, CO by as much as 40%, and increases NOx almost inversely to PM by as much as 10%. Injector coking is slightly greater for biodiesel, with the carbon deposits being harder than diesel deposits.

Fuel properties suggested by ASTM D-975 were reported in most of the articles reviewed, but no ester-specific properties were reported such as percent ester of the fuel, percent glycerol, and alcohol content. The percent of fuel that is ester is one factor that determines the quality of the fuel. The percent of biodiesel which is ester, along with the viscosity, determines the rate at which carbon deposits are formed in the engine combustion chamber (Peterson et al., 1994). Unmodified triglycerides caused polymerization in the piston ring lands of earlier studies.

Materials and Methods

A 20% blend of biodiesel with 80% number two diesel fuel (2-D) was studied using a diesel powered pickup. During the past decade researchers at the University of Idaho have shown that methyl ester of rapeseed when used as fuel in diesel engines is comparable to 2-D. This study was to verify the use of blends of biodiesel in on-road vehicles.

OTHER MODIFICATIONS

While the engine of the test vehicle was unmodified, the vehicle was modified for convenience of running the test. For example, it is known that esters will deteriorate rubber components over a period of time, so the rubber fuel lines were replaced with Viton hose. A low coolant indicator was installed and a red light in the cab was used to warn the operator of low coolant. An hour meter, operated by engine oil pressure, was also added. A biodiesel fuel-tank gauge gave an indication of the fuel level in the biodiesel tank. Additional ammeters and indicator lights indicated whether the fuel mixing system was working properly. The pickup was equipped with a log book to keep daily and long-term records. Also, a maintenance record book was kept, which included the oil samples, dynamometer test data sheets, and any other scheduled or unscheduled maintenance.

FUELS

The feedstock for the fuel in this study was winter rapeseed, Dwarf Essex variety, expelled at the University of Idaho Department of Agricultural Engineering Farm Scale Processing Facility. The blend of fuel was a 20% blend of rapeseed methyl ester (RME), produced at the farm scale processing facility, and 80% 2-D. The RME was processed using equipment and techniques scaled up and modified from prior research at the University of Idaho (Peterson et al., 1983c, 1989, 1997.) The abbreviations used to denote the different fuels were as follows:

RME	100% methyl ester of rapeseed
20RME	20% RME and 80% 2-D
2-D	100% number two diesel fuel

The fuels were characterized by evaluating the parameters required in ASAE EP 552 (ASAE, 1996). The tests for specific gravity, viscosity, cloud point, pour point, flash point, heat of combustion, total acid value, catalyst, and fatty acid composition were performed at the Analytical Lab, Department of Biological and Agricultural Engineering, University of Idaho. The boiling point, water and sediment, carbon residue, ash, sulfur, cetane number, copper corrosion, Karl Fischer water, particulate matter, iodine number, and the elemental analysis were performed at Phoenix Chemical Labs, Chicago, Illinois. The HPLC and titration analysis for total and free glycerol, percent of oil esterified, free fatty acids, and mono-, di-, and triglycerides were performed by Diversified Labs Inc., Chantilly, Virginia.

DIESEL FUEL

While the RME was produced by the Biological and Agricultural Engineering Department at the University of Idaho, the diesel was purchased at convenient filling stations. Phillip's low sulphur diesel reference fuel was used for the diesel fuel in the emissions tests.

DYNAMOMETER TESTING

The vehicle had a break-in period and was dynamometer tested before the biodiesel fuel mixing system was incorporated. The pickup was dynamometer tested approximately every 16 000-24 000 km (10,000-15,000 miles) at Western States Caterpillar in Spokane, Washington. During each dynamometer test, the vehicle was tested with the following: once each with the 20/80 mix, 100% diesel and 100% RME. A full rack torque test was performed with a predetermined set of engine RPM's programmed into the computer to obtain repetitive data. The vehicle was dynamometer tested from 1,600 to 2,650 RPM in 150 RPM increments. A computer recorded vehicle power, vehicle speed, fuel economy, engine RPM, opacity, torque, engine oil pressure, fuel pressure and temperature, exhaust temperature, inlet air temperature, and coolant temperature. Intake manifold pressure and engine blowby were also measured.

PERFORMANCE PARAMETERS

After each dynamometer test the injectors were removed from the engine to check for carbon deposits using the procedure described in *A Rapid Engine Test to Measure Injector Fouling in Diesel Engines Using Vegetable Oil Fuels* (Korus et al., 1985.) The cylinder compression was tested and the injector valve opening pressure was also checked. The Cummins engine has direct access to the combustion chamber and cylinder walls through the injector bore in the cylinder head. A fiberoptic borescope was used to visually inspect the amount of carbon build up on the piston crown and valve heads and to check for any abnormal cylinder wear.

Oil samples were taken at each oil change, which was approximately at each 4800 km (3000 miles) for the biodiesel pickup, and at the convenience of the owners of the control vehicles. All vehicles used Chevron Delo 400 multigrade 15W-40 motor oil. The oil samples were analyzed at a commercial oil analysis laboratory for wear metals, and physical tests were performed, including antifreeze, fuel dilution, water, and viscosity. An infrared analysis for soot, sulfur, nitration, and oxidation of the engine oil was also conducted. The reportable limits for each metal were supplied by the oil analysis lab. Two laboratories were used over the course of the four years of testing (Western States Cat, Boise, Idaho, and Chevron LubeWatch, Spokane, Washington.)

The emissions tests were not performed on the test vehicle described in this report but were conducted with a 1994 Dodge with a 5.9L Cummins diesel engine. The same test fuels were included as part of that test and are included here for completeness since they were conducted during the time frame of the present tests. The emissions tests were conducted at the Los Angeles Metropolitan Transit Authority (LA-MTA) Emissions Testing Facility (ETF) in Los Angeles, California. This facility has instrumentation to measure all regulated emissions: total hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM). Peterson and Reece (1994 and 1996) provided a complete report on these tests including materials and methods, procedures, and results from both methyl and ethyl esters of rapeseed oil.

Two test cycles were utilized for this program. The first was a modified arterial cycle (arterial). The standard form of this test was doubled, creating a 758 s, eight-event cycle. The arterial cycle, as used, had eight repetitions of acceleration to 64 km/h (40 mph) and decelerating to 0 km/h (0 mph). The second cycle was the EPA Dynamometer Driving Schedule for Heavy-Duty Vehicles

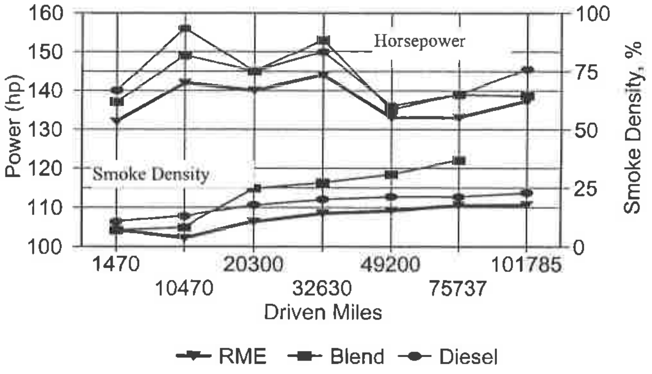

Figure 2–Power and smoke density for each of the dynamometer tests (kW = hp × 0.746, km = miles × 1.609).

could not be locked in direct drive which was required for the dynamometer control system.

Engine Oil Analysis

Table 2 shows the breakdown of data from the oil analysis. The oil was changed in the engine at approximately 4800 km (3,000 mile) intervals and oil samples taken. No oil was added to the engine except during the oil changes. Chevron Delo multigrade SAE 15W-40 heavy duty engine oil was used. The results of the oil analysis showed that there was no unusual deterioration of the engine, or any unusual change in used oil composition. Wear data for the Dodge pickup was at acceptable levels without any significant differences between the sampling reports. Using aluminum and iron as comparison analysis the test vehicle averaged 2.2 ppm for aluminum and 8.0 ppm for iron based on 22 oil samples with an average oil change interval of 5470 km (3,400 miles). The first check vehicle averaged 2.3 ppm for aluminum and 7.1 ppm for iron based on 13 oil samples with an average oil change interval of 7080 km (4,400 miles). The second check vehicle averaged 6.2 ppm for aluminum and 21.5 ppm for iron based on six oil samples with an average oil change interval of 5680 km (3,530 miles). A third check vehicle averaged 5.3 ppm for aluminum and 64 ppm for iron (the third of four samples showed iron at 183 ppm with the others at 20-28 ppm.) based on four oil samples with an average oil change interval of 6360 km (3,950 miles). Check vehicle no. 1 was tested for 203 278 km (126,311 miles), no. 2 for 93 663 km (58,200 miles), and no. 3 for only 19 602 km (16,779 miles).

Performance Parameters

Injector coking was measured after each dynamometer test, but a check vehicle operating on 100% 2-D was not studied during this testing; therefore, an injector coking index is not available. There was very little carbon buildup on the tip of the fuel injectors, either visually or by calculating the area of the coked injector from one interval to the next.

The fuel injectors were sticking when tested at the 79 300 km (49,275 miles) engine performance test apparently due to the fuel filter plugging and rusty fuel being introduced into the injectors. The injectors were cleaned and retested, which resulted in a good spray pattern and the specified valve opening pressure.

Table 2. Partial summary of oil analysis reports

km (miles)	Pb*	Cu*	Fe*	Al*	Na*	Cr*	Viscosity 40°C cSt	% Allowable Soot	Wear Elements‡
2636 (1,638)	1	18	10	2	3			1	N
7229 (4,492)	2	5	10	2	9			14	N
13 137 (8,163)	1	2	7	1	8				A
18 189 (11,302)	3	1	8	2	9			9	A
23 760 (14,764)	1	18	7	1	10			1	A
28 627 (17,788)	1	9	5	1	17			1	A
33 027 (20,522)	1	21	5	1	17			1	A
38 355 (23,833)	2	18	5	7	19				A
43 209 (26,849)	2	4	5	2	6				A
52 820 (32,821)	1	1	8	2	4				A
58 282 (36,215)	1	1	6	2	17				A
74 789 (46,472)	1	6	4	2	3				A
†79 370 (49,318)	2	1	10	4	0	0	13.4		NC
†84 571 (52550)	2	1	7	3	0	0	13.31		NC
†109 172 (67,836)	1	1	6	3	0	0	13.39	0.1	NC
†121 734 (75,642)	1	1	7	2	0	0	13.36	0.1	NC
†126 982 (78,903)	2	1	7	2	4	0	13.43	0.1	NC
†132 951 (82,612)	1	1	7	2	4	1	13.22	0.2	NC
†137 499 (85,438)	2	1	6	2	2	0	12.82	0.02	NC
†142 515 (88,555)	2	1	6	1	3	0	13.7	0.02	NC
†147 876 (91,886)	3	1	5	1	9	0	13.47	0.2	NC
†154 359 (95,914)	12	3	35	5	4	2	14.88	0.6	NC
†164 052 (101,937)	2	1	8	1	6	0	14.07	0.1	NC

* Wear metals are reported in parts per million.

† Indicates oil samples tested at Chevron, all others were done at Western States Caterpillar.

‡ N = normal, A = acceptable, NC = no corrective action required.

The engine cylinder compression was checked at each performance interval. The cylinder compression started at an average 3427 kPa (497 psi) with a standard deviation of 51.4 kPa (7.4 psi) and ended with exactly the same average of 3427 kPa (497 psi) with a standard deviation of 32.5 kPa (4.7 psi) (table 3).

The average beginning valve opening pressure (VOP) was 24 270 kPa (3,520 psi) with a standard deviation of 149 kPa (21.6 psi). The average ending VOP was 24 304 kPa (3,525 psi) with a standard deviation of 172 kPa (25 psi) (table 3).

The internal combustion areas were borescoped at each performance interval. There was no significant visual

Table 5. 1994 emissions data, EPA cycle (no catalytic converter) (gm/mile)

	HC	CO	NOx	CO_2	PM
Diesel	1.254a*	4.497a	6.850a	698.580a	0.411a
20RME	1.002b	3.07b	6.600b	709.13a	0.353a
100RME	0.650d	2.08c	6.313c	703.89a	0.510a

* Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6. Arterial cycle summary

Volume Percent of RME in Diesel Control Fuel	Emissions Percent Increase (+) or Decrease (-) Compared to Diesel Control Fuel		
	20% RME	50% RME	100% RME
HC	–20.2*	–37.2*	–55.6*
CO	–25.3*	–39.1*	–42.2*
NOx	–2.6*	–5.3*	–9.1*
CO_2	0	+0.7	+0.7
PM	–10.4	+7.6	+6.8

* Numbers followed by an * are significantly different from diesel ($P \leq 0.05$).

Table 7. EPA cycle summary

Volume Percent of RME in Diesel Control Fuel	Emissions Percent Increase (+) or Decrease (-) Compared to Diesel Control Fuel		
	20% RME	50% RME	100% RME
HC	–18.0*	NA†	–49.5*
CO	–31.3*	NA†	–54.0*
NOx	–4.1*	NA	–7.6*
CO_2	+1.6	NA	+0.7
PM	–7.6	NA	+21.2*

* Numbers followed by a * are significantly different from diesel ($P \leq 0.05$).

† NA = not available, data was not taken for the 50% RME blend.

higher for the EPA cycle than for the modified arterial cycle. This is probably due to the increased idling time and non-repetitive nature of the EPA cycle. The 100RME showed a slight reduction in NOx, a significant reduction in HC and CO, and a slight increase in PM and CO_2 compared to 1002-D. Table 5 shows the absolute value of emissions measured and tables 6 and 7 show the percent change in emissions compared to diesel control fuel for RME and blends of RME for the arterial and EPA cycles.

ENGINE TEAR DOWN AT 163 800 KM (101,785 MILES)

When the vehicle reached 163 800 km (101,785 miles), the diesel engine was removed from the truck and shipped to Cummins Engine Company in Columbus, Indiana, for analysis. Personnel from the University of Idaho and the Pacific Northwest and Alaska Regional Bioenergy Program were present to inspect the engine at the tear down. The engine obviously reflected the light load condition of use in the pickup. However, it was generally considered to be in a condition which could be characterized as good or better than that which would have been expected with diesel fuel. Engine parts were clean and showed little wear. The detailed description of the engine provided by the Cummins engineers indicated that everything was in good order with the exception of the water pump bearing, a condition not caused by the fuel; the crankshaft seals, which showed some tendency to harden with a resulting slight depression where they make contact with the shaft; rusting of the fuel filter attachment stud; and considerable varnish within the injector pump. Engine inspectors did not think that the varnish was affecting the performance of the pump and that the amount of varnish was probably increased because of the considerable rust exhibited in the mild steel tanks used in the early part of the test.

The following is an excerpt from the report provided by Cummins Engine Company (Branner, 1996).

> FUEL SYSTEM:
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> The fuel pump was run on the pump stand at METC with standard bench test nozzles and found to be in good condition. All fueling was slightly below specification though still within the +/- tolerance with the exception of the idle flow rate which was low. The low flow rate may have been the result of removing the top cover off the pump prior to the stand test. Note, that there were no reported field problems of low engine idle speed. Idle fuel rate was adjusted back to specification before the pump was removed from the stand.
>
> When the top cover was removed from the pump, a large amount of varnishing could be seen on the components inside the pump. Though the pump was still in working order, it is impossible to say what effect the deposits had or will have on the pump and/or engine performance and durability. The pump was not fully dis-assembled and no pre-/post-measurements were recorded.
>
> All the injectors were pop tested at the METC pump lab to check for nozzle opening pressure and spray quality. All injectors were within specification and spray quality was considered good.
>
> POWER CYLINDER COMPONENTS:
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> In general, the power cylinder components were in good condition. Piston deposits were very similar to the previous biodiesel engine. Heavy carbon deposits were found in the areas above the top ring (balcony). No deposits were found below the balcony and the top ring groove was clean. All that could be seen in the top ring groove was a light staining color likely caused by slight fuel and/or oil deposits (varnishing).
>
> Some unusual carbon deposits were found on some of the tips of the pistons' bowls. These unusual deposits were later explained to be due to thin injector shims (0.75mm instead of 1.5mm). These deposits were most likely formed by fuel spray contacting the piston during injection. No cracks were found in the pistons and wear was light in the grooves, skirt and pin bores (all considered normal for this application).
>
> All the piston rings looked to be in good condition. The only problems found were some slight ring manufacturing flaws in the #5 and #6 2nd ring and #6 top ring. In the case of the 2nd rings, small areas of the scraping edge of the ring face were found chipped. In the case of the #6 top ring, there was a small twist at the end gap. None of these problems should have degraded engine performance. Oil consumption appeared to be normal based on reports.
>
> Top ring face contact was around 50%. Side contact was normal with no pitting or chipping found. The 2nd rings had around 25% face contact. Side contact was normal with no pitting found. The oil rings looked to be in very good condition, though there was an unusual deposit found between the rails. These deposits are not viewed as an issue at this time.
>
> The cylinder bores were in very good condition. There was some top and 2nd ring polished areas which are considered normal. Plenty of honing cross- hatching was still visible in all areas of the bore. No other signs of polishing were seen in the bores. The bores were relatively free from dirt scratches.
>
> BOTTOM END COMPONENTS:
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> All the bottom end components were in good condition. Bearings had many hours of life left in them. Some light dirt scratching was found in the bearings which is not considered any problem. The crank shaft had some wear around the areas where the front and rear dust seal rub. The problem was not enough to cause leaks but was a little higher than what is usually seen.

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