Experimental Evaluation of Motor Oils for Use in State Vehicles

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Summary

This report documents four separate tests conducted under the supervision of the North Carolina State University and the North Carolina State Highway Patrol to compare fuel economy and exhaust emissions from typical service vehicles and from research engines operating with a proprietary oil (Royal Purple Oil) and with other competitive oils. The tests are not intended to supersede Society of Automotive Engineers tests required for American Petroleum Institute Certification. The API tests have already been conducted, and have established the suitability of each of the oils for use in modern engines. The current tests were designed to provide data from one-against-one performance tests to be used by the State of North Carolina for economic evaluations.

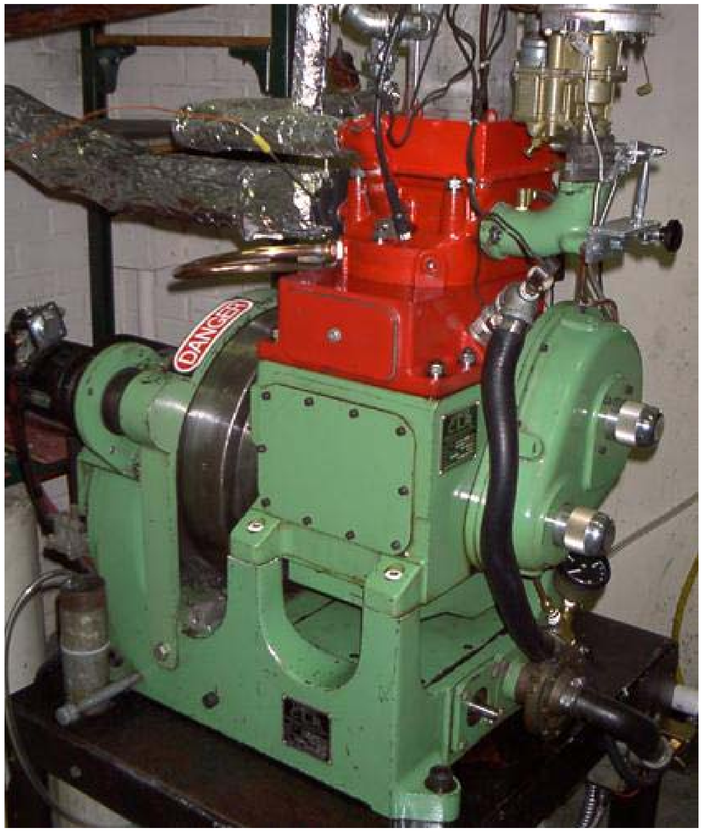
Chassis dynamometer tests known as the Federal Test Procedure (EPA 75 city) and Highway Fuel Economy Test Procedure (HFET) were conducted in an independent laboratory in San Antonio, Texas. These two tests are the only tests recognized by the EPA National Vehicle and Fuel Emissions Laboratory Motor Vehicle Aftermarket Retrofit Device Evaluation Program. The Texas Department of Public Safety provided two 4.6-liter Ford Crown Victoria Highway Patrol Cars for the EPA tests. The patrol cars were year 2,000 models, each with about 30,000 miles of wear. Havoline 10w-30 oil and Royal Purple 5w-30 oil were tested in each vehicle. The tests required about one week to complete. They measured fuel economy and emissions of hydrocarbons, CO, and NO_x. There was no appreciable difference in the results of the fuel economy tests, but emissions were reduced significantly when Royal Purple oil was in the vehicles. Details of the EPA test are provided in this report. Typical results are presented in the Table 1.

<u>Table 1 EPA 75 and HWFET Test Results for DPS1</u>

Test		**Oil**	**emissions (ppm)** HC	CO	NOx	**(%)** CO_2	**economy (mpg)**
EPA-75	Phase 1	Havoline	43.0	285.5	7.75	1.18	18.259
		Royal Purple	44.5	266.3	6.6	1.19	18.297
		(improvement)	(-3.5%)	(6.7%)	(14.8%)		
	Phase 2	Havoline	5.83	34.43	0.22	0.851	16.394
		Royal Purple	5.18	22.8	0.12	0.845	16.51
		(improvement)	(11.1%)	(34%)	(45%)		
	Phase 3	Havoline	10.28	59.83	2.11	0.896	24.82
		Royal Purple	10.55	48.4	1.32	0.90	24.79
		(improvement)	(-2.6%)	(19%)	(37%)		
HWFET		Havoline	13.16	116.3	7.64	1.3325	31.91
		Royal Purple	12.53	102.98	6.76	1.324	32.16
		(improvement)	(4.8%)	(11.4%)	(11.5%)		

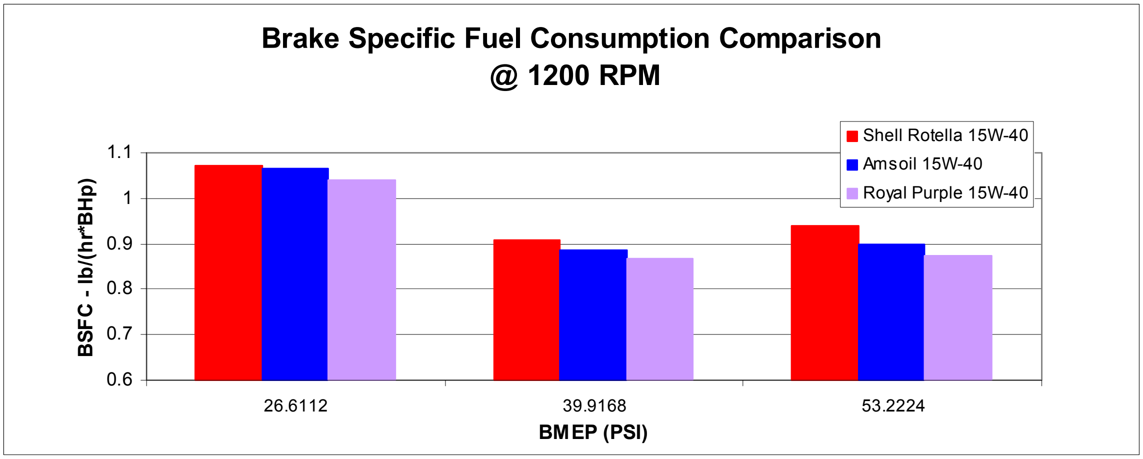
In a separate test, the North Carolina Highway Patrol maintained fuel consumption records for 25 vehicles for an extended period of time. The vehicles in this test were also 4.6-liter Crown Victoria Highway Patrol Cars. Royal Purple 5w-30 motor oil was installed in the patrol cars for a period of about eleven months. The fuel economy for the eleven-month period was compared to that of a previous period in which Havoline 5w-30 oil had been installed in the same vehicles. The routes and driving conditions for the two periods were similar. The test results showed a 2.5% improvement in fuel mileage when Royal Purple oil was in the patrol cars. Details of this test are available from Mr. Ronald Faison of the North Carolina Highway Patrol.

The Coca-Coca bottling company in Raleigh, North Carolina installed Royal Purple motor oil in twelve of their service trucks for a period of about six months. These trucks are equipped with Caterpillar and International diesel engines. Royal Purple 15w-40 oil was compared to Kendall 15w-40. Samples of the engine oil were tested at regular intervals. The trucks were also subjected to snap acceleration smoke tests, and fuel consumption records were kept using a computerized system. The oil sample tests showed that the Royal Purple oil was still in good condition after a period of about 180 days. This is significant because the current maintenance policy is to drain the oil every 90 days. The fuel economy tests for the delivery trucks were inconclusive. The effects of changes in day-to-day driving conditions obscured the limited data available. Also, no conclusions could be drawn from the snap acceleration smoke tests. The smoke test results were strongly dependent on the climatic conditions. The smoke levels in the engine exhausts were greater on hot humid days than on cool clear days, and varied greatly from one truck to another. The engine oil did not appear to have a significant effect on emissions from these well-maintained vehicles. Details of the Coca-Cola bottling company tests are provided in this report.



Carefully controlled engine dynamometer tests were conducted in the Engine Research Laboratory of the Mechanical and Aerospace Engineering Department at North Carolina State University. The tests were conducted under the direction of Professor E. M. Afify by Jarno Kilian and Robert M. Rutherford. Three oils were tested in a single cylinder Cooperative Lubrication Research (CLR) diesel engine, and three oils were tested in a single cylinder CLR spark ignition engine. An engine dynamometer was employed to obtain data at controlled operating conditions (speed and load) following SAE J 1349 engine power test code and SAE J 1312 engine performance and fuel consumption test procedure as well as SAE exhaust emission measurement procedures for diesel and spark ignition engines. The results of engine power output, brake specific fuel consumption, and exhaust emissions obtained for the proprietary oil were compared with those obtained for another synthetic oil and for the most commonly used petroleum based oil. Samples of the oil were analyzed for wear metals and signs of degradation.

Test results from the diesel engine showed that fuel economy and emissions improved when the proprietary (Royal Purple) oil was in the research engines. Fuel consumption was reduced by more than 3% at high engine loads. Soot, CO, and NO_x emissions were reduced by more than 10%.



CLR Gasoline Engine Fuel Economy Measurements

The test results from the CLR gasoline engine were also highly favorable towards the proprietary oil. The Royal Purple oil improved fuel economy as indicated in the figure above, and helped to prevent incomplete combustion and to lower NO_x emissions. The CLR engine test procedure and results are documented in this report.

Taken together, the results from the four independent tests of this work support the following claims of the distributor of the proprietary oil. Extended oil drain intervals are acceptable when Royal Purple oil replaces commonly used mineral oils. Fuel economy improves by as much as 5%. Emissions of CO and NO_x are reduced substantially.

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Introduction

Engine oils consist of base stocks and the various additives that are necessary to produce satisfactory performance[1] . Refined petroleum base stocks are obtained by means of several alternative processes. The lubricating oil stock is vacuum distilled, providing a series of fractions of various levels of volatility and viscosity. The as-distilled base stock fractions may contain nitrogen and sulfur compounds, metals, and aromatics that would adversely affect stability and performance properties, and the ability of various additives to enhance performance. The undesirable components are removed using solvents, or are modified by hydrotreating or hydrocracking. Base stocks that are hydrotreated or hydrocracked typically have higher percentages of saturates and reduced sulfur contents than base stocks that are solvent refined. Hydrocracking increases the proportion of iso-paraffins in place of less desirable hydrocarbons. Waxy materials that would impede low temperature flows are removed by means of a solvent dewaxing process, or by catalytic dewaxing. The final properties of the refined petroleum base stocks, referred to as virgin stocks, depend on the crude oil source and on the refining processes employed.

Synthetic base stocks are produced by chemical synthesis. Several different types of synthetic fluids having simple composition may be produced by chemically processing fractions from petroleum, natural gas, vegetable oil, or animal oil. A synthetic lubricant base stock may consist of any of these fluids, or a mixture of compatible base fluids. Blending is practiced to enhance physical properties. Some synthetic base stocks are compatible with petroleum base stocks, and the two may be combined to form partial synthetic blends that generally perform better than petroleum base stocks, but do not cost as much as pure synthetic base stocks.

The additive agents in petroleum base stocks, synthetic base stocks, or partial synthetic blends are also synthetic materials. They are used at concentration levels ranging from several parts per million to greater than 10% by volume. Additives are designed to protect engine surfaces, to change the oil properties, or to protect the base stocks. Engine protectors include seal swell agents, anti-wear agents, extreme pressure agents, anti-rust agents, corrosion inhibitors, detergents, dispersants, and friction modifiers. Oil modifiers include pour point depressants, antifoam agents, and viscosity index improvers. Base stock protectors include antioxidants and metal deactivators.

Engine and laboratory tests are conducted to establish the performance characteristics of engine oils. Performance categories and classifications have been developed through the efforts of the Alliance of Automobile Manufacturers (AAM), the American Petroleum Institute (API), the American Society for Testing and Materials (ASTM), the Engine Manufacturers Association (EMA), International Lubricant Standardization and Approval Committee (ILSAC) and the Society of Automotive Engineers (SAE). The API Engine Oil Licensing and Certification System was developed through the cooperative efforts of AAM and API to assist engine manufacturers, oil marketers, and consumers to specify, market, and purchase engine oils using simple designations that describe the minimum performance standards for engine oils. Classifications of relevance to the present work include the API “S” series which describes engine oil standards primarily for gasoline engines, the API “C” series which defines standards for diesel engines, and the ILSAC GF series, entitled Minimum Performance Standard for Passenger Car Engine Oils.

Motor oils for passenger cars and light trucks can be certified as energy conserving if they pass a standardized ILSAC GF-3 Sequence VIB test. Energy conserving motor oils must satisfy pass/fail criteria for fuel economy when tested against a base-line oil. The criteria for 0w-20 and 5w-20 oils are 2.0% improvement for oils that have operated under load for 16 hours, and 1.7% improvement for oil aged 96 hours. The criteria for 5w-30 motor oils are 1.6% improvement after 16 hours of oil aging, and 1.3% after 96 hours. In the present work, 5w-30 oils are of interest for use in gasoline engines, and 15w-40 oils are of interest for use in diesel engines.

All of the oils to be tested in this work are API certified. This means that they have all been subjected to a long series of well-controlled tests in independent laboratories, and have demonstrated that they satisfy minimum performance standards. The standards are revised every few years to insure compatibility with the requirements of new engines. When an API Category becomes obsolete, the oil that is certified under this category can still be marketed, but the marketer must provide clear information indicating the product limitations. For example, when API Category SG became obsolete, the following statement was recommended. “This oil is rated API service category SG. It is not suitable for use in most gasoline powered automotive engines built after 1993. It may not provide adequate protection against the build-up of engine sludge, oxidation, or wear. “

The Royal Purple Oil Company has developed a synthetic blend motor oil that is claimed to have performance characteristics that greatly exceed the latest minimum standards. The oil contains an additive that is reported to have the ability to bond to bearing materials to reduce friction and to greatly increase the oil film strength. Timkin load capacity test results provided by the manufacturer show that the proprietary oil has five times the load carrying capacity of conventional mineral oils. Results of severe oxidation tests performed by the manufacturer indicate that the time to failure at high temperature is about an order of magnitude longer than that of other synthetic oils.

The North Carolina Energy Office became interested in the proprietary oil as a possible replacement for conventional oils used in State vehicles. They were especially interested in the prospect of increased fuel economy and reduced emissions. Informal trial tests performed by the North Carolina Highway Patrol had showed that the proprietary oil did not deteriorate as rapidly as the oil already in use. Also, the proprietary oil had already been adopted by the State of Illinois Highway Patrol, by several race-car drivers, and by several long haul trucking firms.

Additional tests were recommended to quantify the reported advantages of the Royal Purple oil. The proprietary oil costs more than conventional oils now being used in State vehicles. Therefore, one-against-one tests were needed to determine whether reported attributes such as increased fuel economy, reduced wear, longer oil drain intervals, and reduced emissions would actually justify the higher initial costs. The present work was conducted to provide data needed for the economic study.

The primary objective of the North Carolina Energy Office is energy conservation. However, the reduction of emissions of soot, CO_2, CO, and NO_x is also of first importance. The environmental impact of vehicles is a major problem that is being addressed with increasing urgency worldwide.

Soot consists of unburned or partially oxidized fuel particles and engine oil. Soot is especially troublesome in the exhaust of diesel engines because it will quickly clog a conventional catalytic converter, rendering it useless. Soot also increases the wear of the engine, especially at the exhaust valve seat. Gases leaving the combustion chamber of diesel engines contain up to 6000 ppm of unburned hydrocarbon compounds. This equates to the equivalent of 1-1.5% of the fuel injected. About 40% of this is unburned or partially oxidized diesel fuel; the other 60 % is composed of partially reacted compounds not present in the original fuel. In the atmosphere, hydrocarbon compounds acts as irritants and odorants, and some are carcinogenic. All components except CH_4 react with other gases to form photochemical smog. Lubricating oil consumption and lube oil particulates have been shown to be a significant contributor to diesel particulate emissions, especially in older engines.

Carbon Dioxide is a normal final combustion product of hydrocarbon motor fuels such as ethanol, gasoline, and diesel. CO_2 is a greenhouse gas that blocks infrared radiation from the earth's surface and contributes to global warming. It also destroys upper level ozone. Man-made CO_2 emissions come primarily from coal burning power plants and from vehicles. The only known way to decrease CO_2 emissions from a gasoline or diesel powered engine is to make the engine more efficient. High technology motor oils can have a small but significant effect on engine efficiency.

Carbon Monoxide (CO) is a colorless, odorless and highly toxic gas with a density close to that of air. It is produced by excessively rich combustion conditions in gasoline engines, but is almost non-existent in diesel exhaust due to the diesel's lean operation conditions. Thus, motor oil effects on emissions of CO are more important in gasoline engines than in diesel engines.

Oxides of Nitrogen (NO and NO_2) are usually analyzed simultaneously in the form of NO_X. Although NOx is a relatively inactive gas in the troposphere, it is an active factor in the destruction of stratospheric ozone. At ground level, it is a significant factor in the creation of smog and acid rain, leading to crop damage, fish and wildlife destruction, and building damage. NO_x emissions are an important issue in the present work.

(1) SAE Handbook, Volume 1, Chapter 12, Fuels and Lubricants, Published by Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa. 15096.

EPA Tests Conducted by Independent Laboratory

Tests[2] recommended by the EPA were conducted by Perkin Elmer Automotive Research, 5404 Bandera Rd., San Antonio,Texas. EPA 75 (city) and HFET (highway fuel economy test) were performed using two vehicles provided by the Texas Highway Patrol. Royal Purple 5w-30 motor oil and Havoline 10w-30 motor oil were tested in the vehicles. The tests were witnessed by Mr. Ronald Faison of the North Carolina Highway Patrol, Mr. Tom Herrmann of the Royal Purple Oil Company, and Dr. J.W. Leach of North Carolina State University. Mr. Jerry Newbury, Manager of Fleet Operations, Texas Department of Public Safety, provided the two 4.6 liter Ford Crown Victoria Highway Patrol cars for the tests. The vehicles are year 2,000 models, each with about 30,000 miles of wear.

The test begins with a test preparation phase in which the test vehicle is placed on a chassis dynamometer and driven through a prescribed sequence to simulate conditions in a city. The vehicle is then kept in an air-conditioned building for at least 12 hours prior to the actual test. During the actual test, the exhaust from the vehicle is caught in bags and analyzed. The EPA 75 test consists of a cold start, and a 30-minute sequence of accelerations and stops to simulate driving in a city. Each phase of the test must be completed within a few seconds of a prescribed time, or the test is invalid. Also, the instrumentation is calibrated after each phase of the test using a known sample of gases. The instruments must measure the known sample within a prescribed tolerance, or the test is invalid. If the EPA 75 test is successful, it is followed by the HFET test. The HFET test is the same as the EPA 75 test, except that the test sequence simulates highway driving.

The test vehicles were delivered to the Independent Laboratory on the morning of October 9, 2000. The laboratory was forced to delay the start of the test by one day because a component of the test apparatus failed. A new part was ordered from Chicago, and was installed on the morning of Oct. 10. The oil was drained from the test vehicles on the afternoon of October 10, 2000. New Havoline 10-w-30 oil and new oil filters were installed. The vehicles were then run through the test preparation sequence and placed in the air-conditioned environment. On the morning of Oct. 11, a Ford Crown Victoria provided by Perkin Elmer Automotive Research was driven through the EPA 75 sequence to make sure that all of the test equipment was operating properly. The trial run was successful. The first test vehicle, designated DPS1, was then tested. This test was invalid because of instrumentation problems. The tests for the second test vehicle, designated DPS2, were successful.

The Havoline oil was drained from DPS2 and replaced with Royal Purple Oil. The filter was also changed. The vehicle was then placed on the chassis dynamometer to simulate highway driving for 50 miles. The Royal Purple Oil was drained and replaced with new Royal Purple Oil. The filter was also changed. The two vehicles were then subjected to the test preparation sequence and placed in the air conditioned environment. The second set of EPA 75 and HFET tests were successfully completed on DPS2 on October 12. Also, DPS1 was tested successfully with Havoline oil on Oct. 12. The test of DPS1 with

Royal Purple oil was completed on October 14, 2000. The test results are summarized in the tables below.

Table 1 EPA 75 and HWFET Test Results for DPS1

Test		Oil	emissions (ppm) HC	CO	NOx	(%) CO_2	economy (mpg)
EPA-75	Phase 1	Havoline	43.0	285.5	7.75	1.18	18.259
		Royal Purple	44.5	266.3	6.6	1.19	18.297
		(improvement)	(-3.5%)	(6.7%)	(14.8%)		
	Phase 2	Havoline	5.83	34.43	0.22	0.851	16.394
		Royal Purple	5.18	22.8	0.12	0.845	16.51
		(improvement)	(11.1%)	(34%)	(45%)		
	Phase 3	Havoline	10.28	59.83	2.11	0.896	24.82
		Royal Purple	10.55	48.4	1.32	0.90	24.79
		(improvement)	(-2.6%)	(19%)	(37%)		
HWFET		Havoline	13.16	116.3	7.64	1.3325	31.91
		Royal Purple	12.53	102.98	6.76	1.324	32.16
		(improvement)	(4.8%)	(11.4%)	(11.5%)		

The total hydrocarbon and CO emissions from DPS1 were generally higher than those from DPS2, particularly for the highway tests. The NOX emissions for DPS1 were generally lower than those of DPS2. This would indicate that combustion is more complete in DPS2. The engineer from Perkin Elmer stated that incomplete combustion in DPS1 probably caused the test difficulties. However, the fuel economy results for the two vehicles were almost identical. The results from both vehicles show that Royal Purple oil does decrease CO emissions.

The city test CO emissions for DPS2 were reduced by more than 20%, and the highway CO emissions were reduced by 60%. For DPS1, the city test CO emissions were reduced by about 20%, and the highway C0 emissions were reduced by about 10% . The hydrocarbon emissions for DPS2 were reduced by about 20% in both tests. For DPS1 the hydrocarbon emission results are not conclusive. NOx emissions from DPS2 were also inconclusive. For DPS1, the NOx emissions were reduced by more than 10% with Royal Purple Oil. The Royal Purple oil did not appear to affect CO2 emissions or fuel economy in these tests.

Table 2 EPA 75 and HWFET Test Results for DPS2

Test		Oil	emissions (ppm) HC	CO	NOx	(%) CO2	economy (mpg)
EPA-75	Phase 1	Havoline	39.9	203.9	8.26	1.20	18.206
		Royal Purple	33.3	160.3	6.3	1.19	18.363
		(improvement)	(16.5%)	(21%)	(24%)		
	Phase 2	Havoline	7.56	24.77	1.52	0.838	16.647
		Royal Purple	6.16	14.12	1.31	0.843	16.608
		(improvement)	(18.5%)	(43%)	(14%)		
	Phase 3	Havoline	9.31	41.84	3.49	0.847	26.35
		Royal Purple	8.09	31.8	4.69	0.890	25.06
		(improvement)	(13.1%)	(24%)	(-34%)		
HWFET		Havoline	7.29	15.42	10.02	1.35	31.68
		Royal Purple	5.93	5.86	12.37	1.31	32.55
		(improvement)	(18.6%)	(62%)	(-23%)		

The engineers from the independent laboratory stated that results from their tests are repeatable within 2%. Thus, the EPA tests indicate that Royal Purple Oil does have the ability to reduce CO and total hydrocarbon emissions.

(2) United States Environmental Protection Agency Publication EPA 420-B-98-003, National Vehicle and Fuel Emissions Laboratory, 2565 Plymouth Rd., Ann Arbor, MI, 48105

Tests in Diesel Delivery Trucks

The Royal Purple oil was installed in twelve service trucks operated by Coca Cola Bottling Company, 2200 South Wilmington St., Raleigh NC 27603. Four of the trucks were equipped with Caterpillar 3116 engines, and eight were equipped with International DT-466 engines. The trucks were filled with 15-w-40 oil during May 2001, and the oil was drained from the trucks at the end November, 2001. The three main objectives were:

1. to measure the engine wear metals in the oil over an extended period of time.
2. to determine the effect of the proprietary oil on fuel economy.
3. to measure smoke emissions in SAE J1667 snap acceleration tests.

The tests were made possible due to the cooperation of Mr. Gerry Beattie, who is the regional fleet manager for Coca Cola, and Mr. Robert Pendergraph, who is the service department manager at the Raleigh facility. Mr. Pendergraph collected samples of the oil from each vehicle at regular intervals, and had the samples analyzed by two independent laboratories. Also, a new computerized fuel tracking system was installed at the Raleigh facility so that the fuel consumption of the twelve test vehicles could be compared to that of other trucks in the fleet. Each vehicle was subjected to standardized SAE J1667 snap acceleration tests in April, June, and October.

The maintenance policy at Coca-Cola Bottling Co. is to change the oil in the service trucks every 90 days. However, to obtain data for evaluating the possibility of extended intervals between oil changes, the proprietary oil was left in the test vehicles for about 180 days. The individual trucks were driven between 3,000 miles and 9,000 miles during this period. The table below compares the wear elements in the last oil samples for each truck to acceptable values published by an independent laboratory[3].

Coca-Coca Bottling Company Service Truck End of Test Wear Metal Data Summary

Truck I.D.	Engine	Oil Sample Date	Mileage at End	Oil mi.	Wear Elements (PPM) Cu	Fe	Cr	Pb	Al	Si	Sn
2280	3116	11/27/01	138,865	4,046	5	12	2	1	4	2	4
2289	3116	11/27/01	135,900	5,124	8	14	4	5	3	4	3
2292	3116	12/19/01	94,856	5,826	5	22	2	4	7	6	2
5783	DT466	12/19/01	60,198	3,000	7	13	0	6	4	6	1
5784	DT466	12/19/01	40,881	8,331	13	44	1	14	6	7	3
5785	DT466	12/19/01	71,814	7,367	13	61	1	14	6	7	2
6523	DT466E	12/19/01	45,977	7,075	13	39	1	9	5	7	2
6653	444E	12/19/01	70,403	5,921	11	21	0	9	4	6	2
9508	3116	12/19/01	134,302	3,025	11	24	1	6	5	6	3
11458	DT466E	12/19/01	30,747	7,130	10	29	0	8	4	9	2
11459	DT466E	12/19/01	22,000	4,886	12	27	1	8	4	6	2
11460	DT466E	12/19/02	48,042	9,245	28	47	1	10	5	9	2
		Acceptable values[3]			30	145	10	20	15	25	20

(3) Ana-Lab Publication, included in Appendix C

The table shows that wear metals in all of the samples of oil taken at the end of the test were within acceptable levels, and the independent laboratory indicated that the oil was still in usable condition. Reference (1) states that wear metal levels are greatly affected by the age of the vehicle, the operating load, driver habits, road conditions, oil filter type, the hours and miles on the oil, and the oil type. This would explain the variations in the data for the individual units in the table.

Truck number 11460 is the only vehicle for which a wear metal approached the published acceptable level. After 9,245 miles, the copper wear metal level of 28 ppm in the oil sample is near the acceptable limit of 30 ppm. However, this does not necessarily indicate excessive wear in the engine of this vehicle. The high copper concentration in the final oil sample from this truck is probably due to accumulations from low wear rates over an extended period of time. The detailed test data in the appendix show that the wear rates did not increase significantly during the final months of the test. This indicates that the oil has not yet reached the end of its useful life.

The relatively low concentrations of wear metals in oil samples after extended drain intervals show that the proprietary oil has done a good job of lubricating the delivery truck engines. Test data for other oils are not available for direct comparison. The fleet manager was reluctant to leave the standard oil in his trucks for more than 90 days. When asked for his opinion, he stated that he believed without a doubt that the proprietary oil does last longer than the standard oil. However, to be conservative, he would not leave the proprietary oil in his trucks for more than 90 days on a regular basis. His personal opinion is that the reduced wear in 90 days is not enough to justify the additional cost.

The independent laboratory analyses of the oil from the delivery trucks indicate that a drain interval of at least 180 days is satisfactory under the present operating conditions. This would change the economics in favor of the proprietary oil. However, the reluctance of the experienced fleet manager to risk damage to his vehicles by extending the drain interval is evidence that additional data may be needed.

Coca-Coca Delivery Truck Fuel Consumption Data Summary

Truck ID	Engine Type	Month Tested	Oil Brand	Miles Traveled	Gallons Consumed	Avg. mi./gal.	Improvement
6653	444E	May	Kendall	943.0	150.42	6.27	
		Sept.	Royal Purple	748 .5	125.38	5.97	- 4.8 %
11460	DT466E	May	Kendall	1418	231.16	6.13	
		Sept.	Royal Purple	1290	206.22	6.24	1.8 %
5784	DT466	May	Kendall	1287	209.95	6.13	
		Sept.	Royal Purple	1111	173.59	6.40	4.4 %
6523	DT466E	May	Kendall	1104	200.69	5.50	
		Sept.	Royal Purple	854	149.71	5.70	3.6 %

The fuel economy tests of the delivery trucks were inconclusive. Records of fuel consumption and truck mileage were maintained for a few weeks in May before the proprietary oil was installed, and for the entire month of September. Problems with the new fuel tracking system prevented the maintenance engineers from obtaining complete records during May. As a result, direct comparisons of fuel consumption can be made for four vehicles only. The data, which are summarized in the table above, show that fuel economy improved by a few percentage points in three of the vehicles, and declined in the fourth. The weekly fuel mileage averages for a given vehicle, given in the appendix, vary by more than 10%. This indicates that day-to-day variations in loads and driving conditions have a significant effect of fuel consumption. The total of the miles traveled by the four vehicles during May is about 18% higher than the total for September. The test conditions were not the same. Thus, we do not believe that any valid conclusions regarding fuel economy can be drawn from the limited data collected during this test.

SAE J1667 snap acceleration smoke tests[(4)] were conducted on three separate dates to measure the opacity of the exhaust gases from each truck. This test is used by regulatory and enforcement authorities responsible for controlling smoke emissions from heavy-duty diesel-powered vehicles. It is a non-moving vehicle test that can be conducted along the roadside or in a truck depot. The test is designed to identify excessive smoke emitters, and to provide an indication of the state of maintenance and/or tampering of the engine and fuel system. It does not replicate the federal engine certification smoke cycle.

The opacity of the exhaust gases is measured using a smoke meter that is attached to the truck exhaust pipe. The smoke meter contains a sensor that records the strength of a light beam that has passed through the exhaust gases. The tests of the delivery trucks were conducted in the parking lot of the bottling company, which is about 200 ft. above sea level. The trucks were tested late in the afternoon as they returned home from a day on the road. Prior to the test, the truck engine was allowed to idle for several minutes until the coolant temperature approached a steady value of about 180^{o}F.

The actual snap acceleration test takes about 15 minutes. The truck engine idles for most of this time period. At regular intervals, the accelerator is depressed causing the engine speed to increase rapidly. The accelerator is then released suddenly, and smoke appears in the exhaust gases. The smoke meter records the opacity. The test is repeated 12 times for each truck, and the smoke meter is recalibrated for each data point. The smoke meter employed in the tests of the delivery trucks is a CalTest 1000 model. It meets SAE J1667 technical specifications, including half-second algorithm protocols. The meter is preprogrammed so that the SAE J1667snap acceleration test is software controlled, eliminating user errors.

The delivery trucks were tested using the smoke meter on April 4, before the proprietary oil was installed, and the tests were repeated on June 13 and October 3. The average opacity values recorded for each test are summarized in the table below. Opacity is defined as the percentage of light transmitted from a source that is prevented from reaching a light detector. Most of the States now permit[(5)] opacity values to 40% for vehicles manufactured after 1990, and opacity values to 50% for vehicles manufactured prior to 1991. Cut points in high altitude States may be greater than this. The table shows that the measured smoke levels in the delivery truck exhausts were relatively low, and varied by only a few percentage points throughout the test period.

A previous test involving 24 diesel-powered vehicles in California [(4)] showed that ambient conditions have a large effect on as-measured snap acceleration smoke results. Eight tests were conducted on each of the 24 vehicles at six different elevations. Post-test analyses indicate that dry air density is the most important variable. However, engines with different combustion and smoke control technologies had different degrees of sensitivity to changes in air density.

The small differences in opacity measurements in the present work are probably due to variations in ambient conditions on different test days, and not to the effects of the engine oil. The opacity measurements for 6/13/01 are generally higher than those for the other two test days. This is certainly not an engine oil effect, because the same oil was in the trucks for two of the test days. However, the dry air density was lower during the summer day than in the Spring or Fall. Overall, the smoke levels increased slightly for some trucks, and decreased for others. The data indicates that the engine oil does not have a large effect on smoke levels in snap acceleration tests for well-maintained trucks. This test does not appear to have any relevance in the present work.

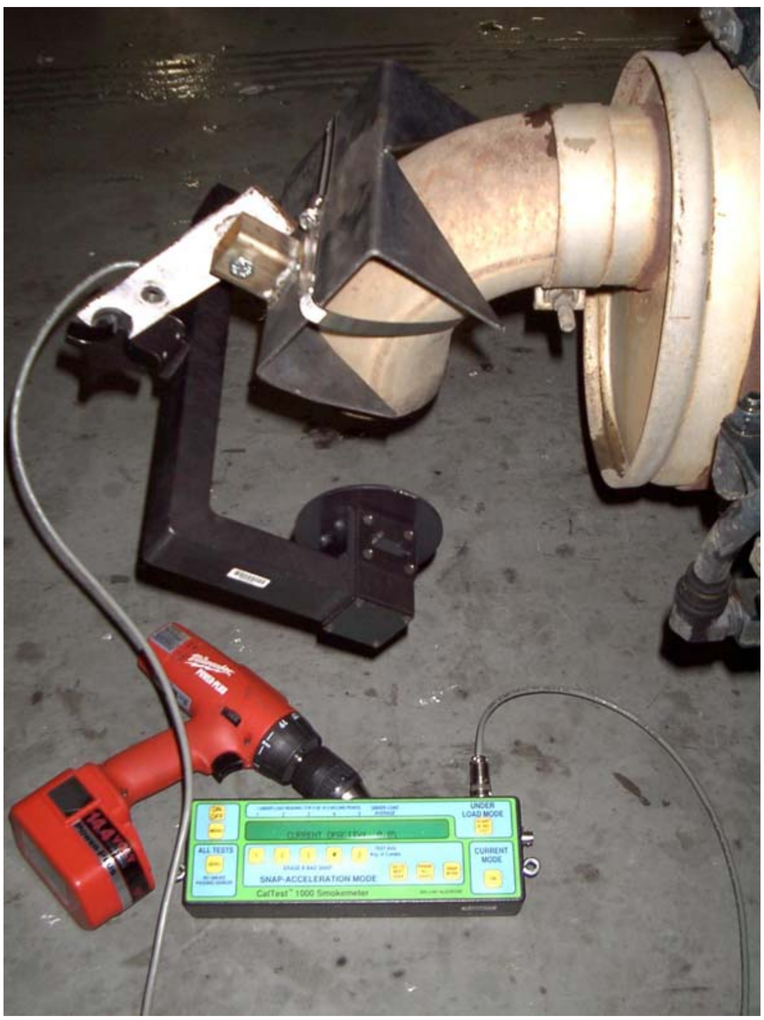
Coca-Cola Bottling Company Snap Acceleration Smoke Test Data Summary

Truck		Test Date, 4/4/01		Test Date, 6/13/01		Test Date, 10/3/01	
I.D.	Engine	mileage	opacity	mileage	opacity	mileage	opacity
2280	3116	134,001	1.3	135,405	1.3	137,737	2.6
2289	3116	129,972	3.0	131,750	4.6	134,398	6.3
2292	3116	87,708	1.5	90,185	1.6	94,061	3.8
5783	DT466	56,603	11.2	57,777	16.1	59,402	8.9
5784	DT466	31,258	9.0	34,443	5.3	truck unavailable	
5785	DT466	62,990	2.6	65,557	4.2	69,776	6.0
6523	DT466E	37,597	15.8	40,250	12.0	44,881	7.4
6653	444E	63,046	2.6	65,660	6.3	69,287	5.4
9508	3116	130,647	12.5	131,920	22.3	134,173	14.5
11458	DT466E	22,124	4.7	25,220	6.9	29,782	7.3
11459	DT466E	15,981	4.8	17,845	5.6	20,978	7.7
11460	DT466E	36,823	4.1	41,111	6.1	47,562	7.1

(4) "Society of Automotive Engineers (SAE) J1667 Recommended Practice, Snap Acceleration Smoke Test Procedure for Heavy-Duty Powered Vehicles," Available from SAE Publications, 400 Commonwealth Dr., Warrendale, PA, Feb. 1996.

(5)"Establishment of Smoke Opacity Cut Points for SAE J166," EPA Cooperative Research Program, Gary W. Pollak, Program Manager, Available from SAE Publications, 400 Commonwealth Dr., Warrendale, Pa, Nov. 1998


Coca-Cola


ON
OFF
UNDER
LOAD MODE
ALL TESTS
CURRENT
MODE
SNAP-ACCELERATION MODE
CalTest™ 1000 Smokemeter

Single Cylinder Diesel Research Engine Tests

This section documents tests conducted at the North Carolina State University using a CLR research engine designed for oil tests. Shell Rotella 15w-40 petroleum based oil, Amsoil 15w-40 synthetic based oil, and Royal Purple 15w-40 synthetic blend oil were tested in the engine.

All three of the oils are certified through the American Petroleum Institute (API) Engine Oil Licensing and Certification System (EOLCS). This is a voluntary licensing and certification program that authorizes engine oil marketers who meet API requirements to use the API Marks on their containers. Motor oils meeting the API requirements are recommended by vehicle manufacturers. Performance requirements, test methods, and pass/fail limits are cooperatively established by engine manufacturers, and by technical societies such as the Society of Automotive Engineers (SAE) and the American Society for Testing and Materials (ASTM). The EOLCS is backed by an on-going monitoring and enforcement program. Additionally, the program ensures that the API registered symbols are properly displayed on containers and convey accurate information to consumers.

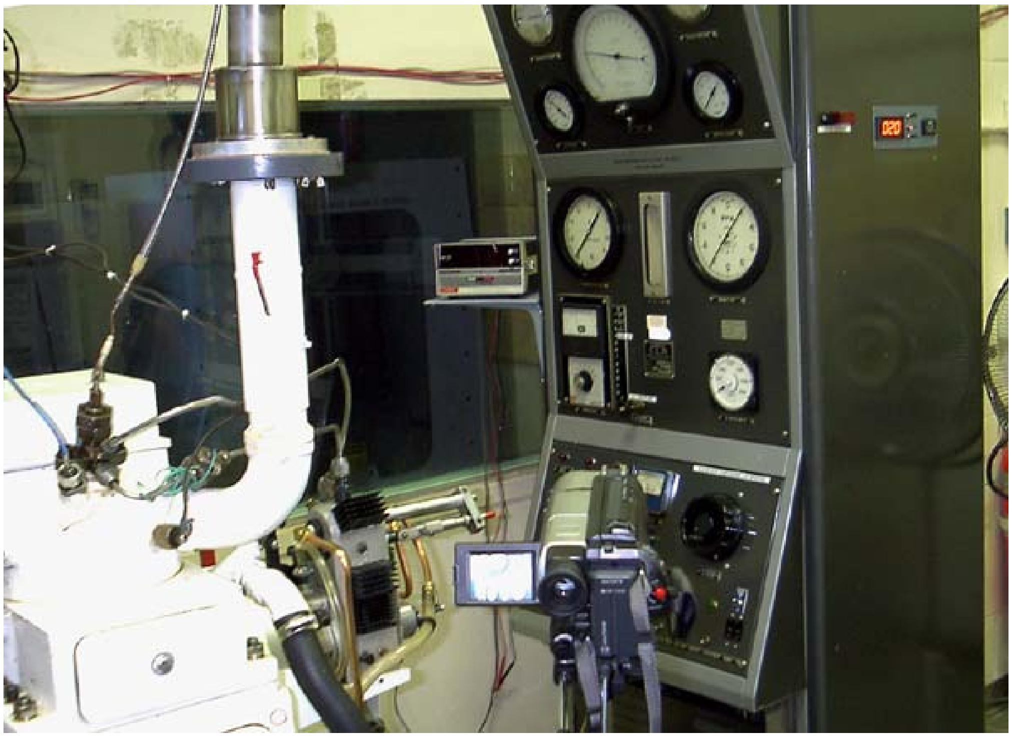
Since the oils tested herein are already certified for use in diesel engines, the present work is not meant to check the oils' ability to meet engine manufacturer's requirements, but to quantify differences in fuel consumption, emissions and engine wear. The goal of the present work is to determine whether high performance oils are worth the additional cost. The high initial cost can be justified if the oil substantially reduces emissions, improves fuel economy, reduces wear, or lasts longer

Since motor oil is one of the few regular maintenance items on a diesel engine, it plays a significant part in determining the operating cost of the engine by affecting engine durability and fuel consumption. Additionally, new regulations require diesel engines to have reduced emissions, which can also be affected by the composition of the motor oil. Over the last two decades, synthetic motor oil usage has become more widespread, and synthetic oil marketers claim that there are substantial improvements in the areas of:

- High shear stability
- Corrosion prevention
- Improved fuel economy
- Reduced oxidation
- Extended drain intervals
- Reduced oil consumption
- Reduced emissions

These attributes are mentioned by Royal Purple and by Amsoil as arguments for purchasing their respective synthetic oils.

Research Project Equipment



Diesel Engine

The research was performed on a Laboratory Equipment Corp. (Labeco) CLR engine, which is a high speed four stoke designed primarily for oil test and research work. The CLR is a single cylinder engine with a bore and stroke of 3.8125” x 3.750” respectively. The displacement is 42.5 cu. in. and has a compression ratio of 16.7:1. The oil sump holds between 2-4 pints, and the oil pressure is adjustable. The engine is water-cooled and is of the “Mexican Hat” bowel-in-piston type. The engine is fed by a Bosch APE1B diesel pump which allows the diesel injection timing to be adjusted while the engine is running so that various injection phenomenon can be studied. Adjustments in the amount of fuel delivery per stroke at varying load and speed are made by rotating the pump plunger in its barrel. The diesel pump is driven by the diesel engine’s cam shaft. The throttle setting is adjusted manually with micrometer style readout.

Before testing began, the engine was completely torn down and rebuilt to “as-new” specifications with a new piston, cylinder sleeve, all new bearings, new valves and new valve oil seals. The engine was then broken in accordance with the LABECO instruction manual before the oil testing started. The variable fuel injecting timing mechanism was locked for this research to insure consistent injection timing over the course of the research. The diesel pump and injector were also rebuilt and calibrated before testing .

- Dynamometer

The engine load is measured using an Eaton Eddy Current dynamometer, the rotor of which is coupled to the engine crankshaft. The dynamometer lever arm is designed so that it impresses force on an Emery AD-1 hydraulic load cell when the dynamometer housing tries to rotate. The housing will tend to rotate due to an induced electromotive force between the moving rotor and the housing itself. Eddy currents are generated in the metal rotor as it turns in the magnetic field created by the variable supplied voltage. These currents cause a force to be developed between the rotor and the dynamometer housing, imposing a load on the engine. The hydraulic load cell is connected to a boron tube/needle indicator, which displays the amount of load applied to the engine in pounds.

The dynamometer is calibrated before testing begins. It is controlled by an Eaton Mark III solid-state controller. This system uses feedback, or closed loops to linearize and stabilize its performance characteristics. This assures highly accurate load application to the engine even over hours of use. From the torque measurement and the engine speed the power produced by the engine can be calculated. It is then converted to brake mean effective pressure (BMEP) and used for the analysis of the oil's performance in terms of emissions and fuel consumption.

- Instrumentation

The instrumentation of the engine includes the following:
- Calibrated Electronic Tachometer with 10RPM graduations
- Manometer displaying the mass airflow into the engine
- Dynamometer load cell readout
- Dynamometer adjustment and status displays
- Oil Pressure
- Crankcase Vacuum
- Multi-channel thermocouple readout for measuring:
- Engine water inlet temperature
- Engine water outlet temperature
- Crankcase oil temperature
- Ambient air temperature
- Exhaust gas temperature
- Fuel consumption timer

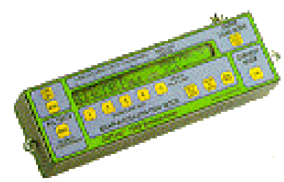
Emissions Analyzer

Engine exhaust emissions are tested by the use of a Nova Analytical Systems Inc. Autocheck Model 975 Exhaust Emission Analyzer. The Autocheck 975 is the latest, state-of-the-art portable engine exhaust analyzer that uses non-dispersive infra red

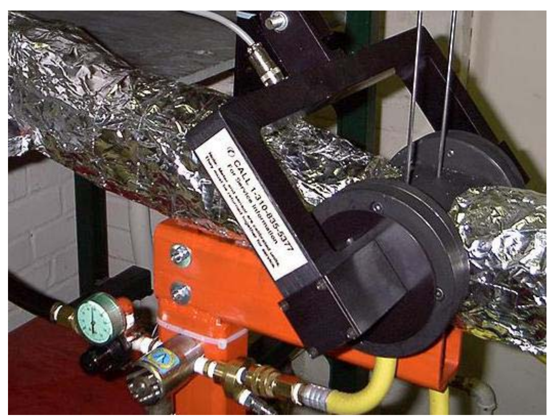
(NDIR) detector technology to determine CO, CO2 and HC concentrations. Oxygen is detected by long life electrochemical sensors. The analyzer allows for continuous measurement of CO, CO2, HC, O2 and NOx gasses. The internal sensors are approved by world recognized EPA ASM, AMS/BAR97 and OIML CLASS 0&1 tests. The sensors were replaced at the beginning of the project and are guaranteed to perform for two years from the date of installation. The analyzer was calibrated before each of the tests began using National Welders Research Grade custom gases.

Soot Level Meter

A CalTest 1000 Smokemeter was used, which meets SAE J1667 technical specifications, including 1/2 second algorithm protocols. The meter's preprogrammed SAE J1667 snap-acceleration test is software controlled, eliminating user errors. It was used in conjunction with a soot sight box that was custom built for laboratory testing where an open tailpipe is undesirable.

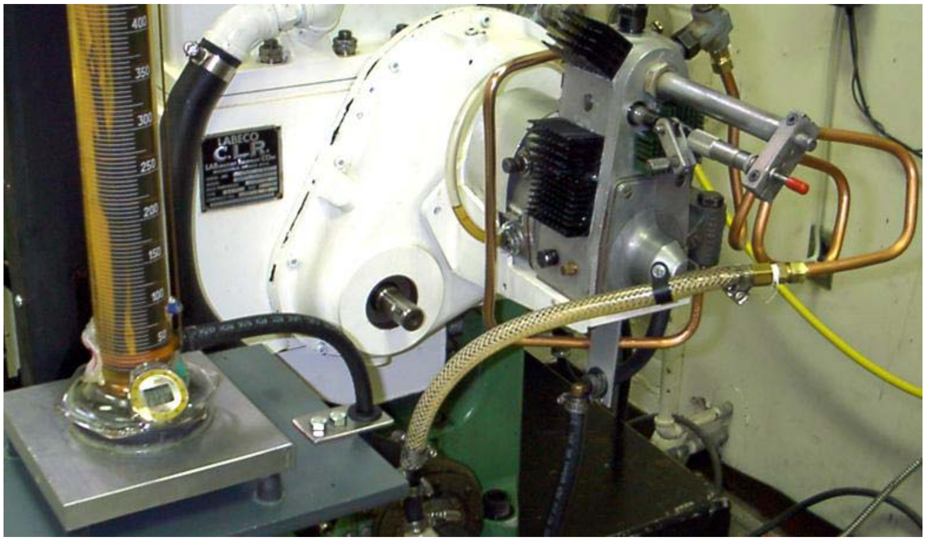


The smoke meter was used in the research laboratory through the use of a custom portal consisting of two view ports made of laboratory grade boron glass. The glass was kept clean by having compressed air between the exhaust gas and the view port, effectively shielding it against deposits. The setup is shown in the picture to the right.



Fuel Consumption Timer

Specifically for this research, a device was built that measures the time it takes for the diesel engine to consume 100 ml of No. 2 diesel fuel. It consists of a graduated cylinder that is filled with the diesel. A float, equipped with a magnet triggers two reed switches, one at the beginning of the 100 ml run and one at the end of the 100 ml run. The accuracy of the device was within SAE tolerances (3% maximum) at 2.3% repeatability.



Development of Testing Protocols

Several SAE Test standards were used to create a test that is meant to be more realistic in terms of real-world application of results to road-going vehicles. The foundation is the SAE J304 diesel test standard, which was specifically written for the L-38 test engine. The SAE J1349 and SAE J1995 Engine Power Test Codes were incorporated into the J304 protocol. The testing procedure is outlined in a later section. Soot Testing was done in accordance with the SAE J255a Diesel Engine Smoke Measurement. Special attention was paid to the tolerances on engine RPM and repeatability of fuel consumption measurement data.

Research Tolerances

Engine Speed: ± 10 RPM
Difference in coolant temperature ± 2 ^oF
Oil Pressure ± 2 PSI
Crankcase vacuum 3 ± 0.5" H_2O
Specific humidity ± 2%
Water temp from head 160 ± 5 ^oF
Engine Oil Temp 180 ± 5 ^oF

Single Cylinder Diesel Testing Procedure Developed and Used

- Clean out emissions analyzer line with compressed air with analyzer disconnected
- Clean view ports on soot box with Windex and lint-free tissue
- Check engine oil level
- Check accessory case oil level
- Check dynamometer bearing oil level
- Check vacuum pump oil level
- Check that exhaust system valve is turned off
- Replace cotton pre-filters in exhaust measurement system
- Check that the final filter on the emissions tester is not contaminated
- Fill fuel measurement cylinder with diesel
- Turn water supply on, allow pressure to build in expansion tank
- Turn engine exhaust stack fan on
- Turn on soot box air supply, make sure that at least 80 PSI static air pressure is available
- Check that dynamometer excitation is turned to zero
- Energize all electrical systems, including dynamometer power
- Adjust water level in coolant tower to center mark
- Turn on battery charger
- Turn on crank case vacuum pump, allow vacuum to start building on gage
- Start engine
- Adjust crankcase vacuum for 4 inches water on gage
- Allow to run at no-load for 5 minutes at 1000 RPM
- Turn off battery charger
- Over next 25 minutes, gradually increase excitation and engine speed to speed required for testing
- For 30 minutes, run engine at test load and speed to reach steady state
- Check water level in cooling tower
- Make sure that the engine temperature is stable for 5 minutes before beginning testing
- Take soot, emissions and fuel consumption measurements at two different RPM settings and three different loads (we used 1200, 1600 RPM and 10,15 and 20 lb. of load)
- When switching between loads, wait 15 minutes for the engine temperatures to reach steady state
- When switching between Rpm's, wait 30 minutes for the engine to reach steady state.
- Fuel Measurement:
  - Measure time taken for engine to use 100ml of BP No.2 Diesel Fuel
  - Taken with stopwatch between marks on graduated cylinder
  - Maintain engine RPM within 10 RPM during test

- Soot Measurement
  - Complies with SAE J1667 Snap Test
  - Turn meter on with sensor raised above soot box
  - Follow instructions on screen
  - Maintain engine RPM within 10 RPM during test

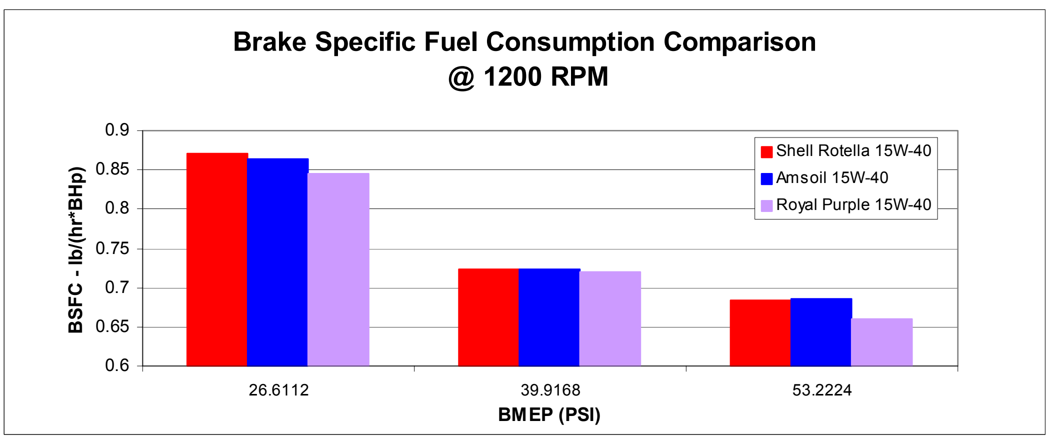
- Emissions Measurement

- Make sure exhaust system valve is closed
- Disconnect the line at the meter
- Turn emissions meter on, allow meter to complete zero span calibration
- Reconnect line
- Start emissions testing, open exhaust system valve
- Make sure that there is 2.0 SCFH of flow through the meter. If not, a filter is clogged, if too high, adjust with valve
- Maintain engine RPM within 10 RPM during test
- Meter beeps when test is complete, print out the results
- Close exhaust system valve

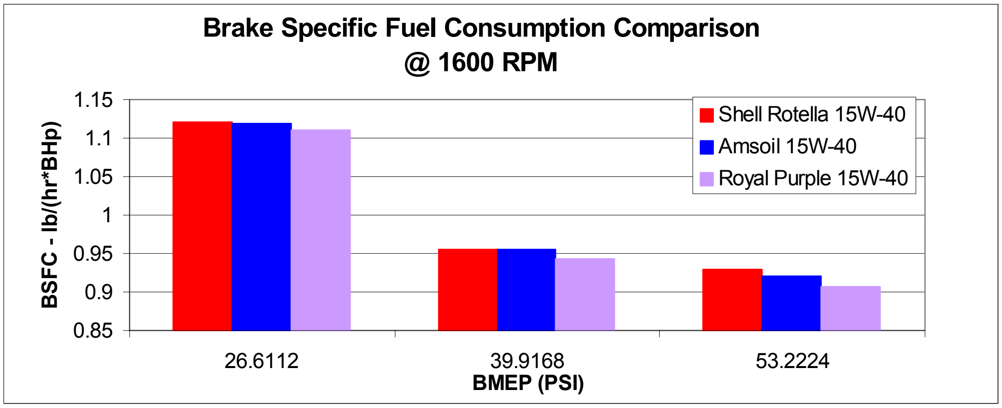
- After testing is complete, run engine at no load for 10 minutes to allow to cool down
- Stop engine
- Turn off all electrical devices
- Turn off exhaust stack fan
- Turn off soot box air supply
- Turn off water supply
- Enter data in spreadsheet templates on computer

Data Summary for the three oils tested in the Labeco Research Diesel Engine

1) Fuel Consumption Comparison Summary:

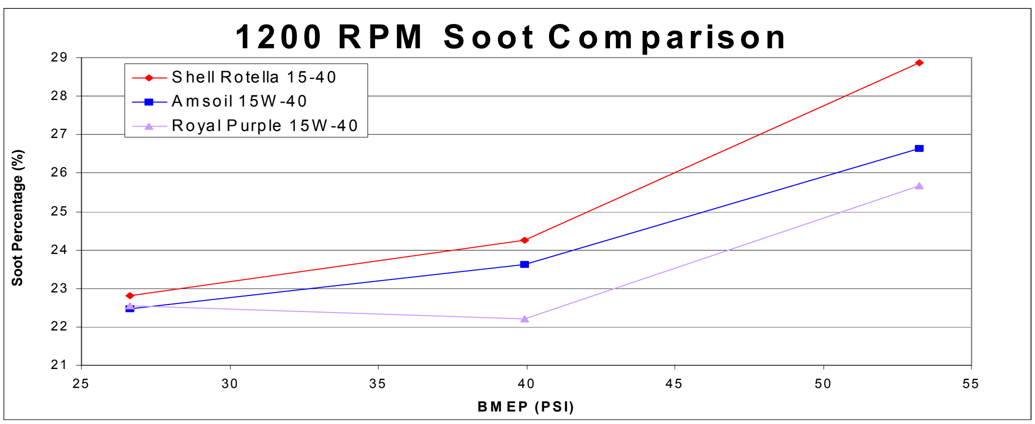


At each load level, the Royal Purple showed significantly lower fuel consumption than either the Amsoil or Shell. At 1200 RPM, the greatest improvement of the Royal Purple oil was over Amsoil with a fuel consumption reduction of 3.37%. The next greatest improvement was against Shell Rotella with a 3.68% improvement. These were both achieved at a BMEP of 53.2224 PSI, which corresponds to a 20lb load.

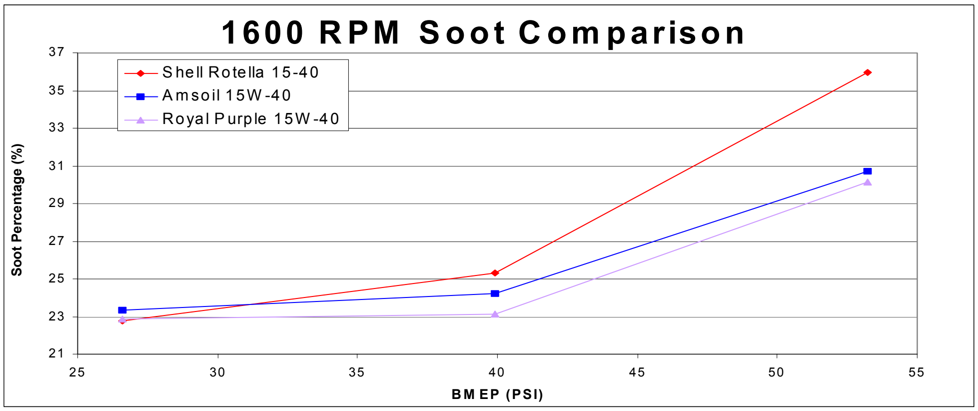


The Royal Purple results at 1600 RPM again indicated lower fuel consumption than either Shell or Amsoil. The greatest improvement of the Royal Purple oil was over Shell Rotella with a fuel consumption reduction of 2.48%. The next greatest improvement was against Amsoil with a 1.48 % improvement. These were both achieved at a BMEP of 53.2224 PSI, which corresponds to a 20lb load.

2) Soot Generation Analysis Summary

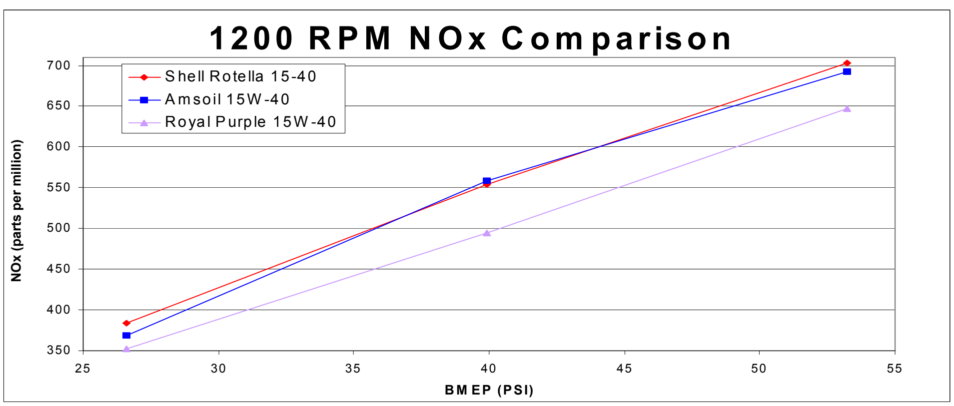


At 1200 RPM, the Royal Purple oil performed better at all loads than the other two oils, especially at high load. The greatest soot reduction was against Shell Rotella with a decrease in soot generation of 11.75% at a BMEP of 53.2224 PSI.

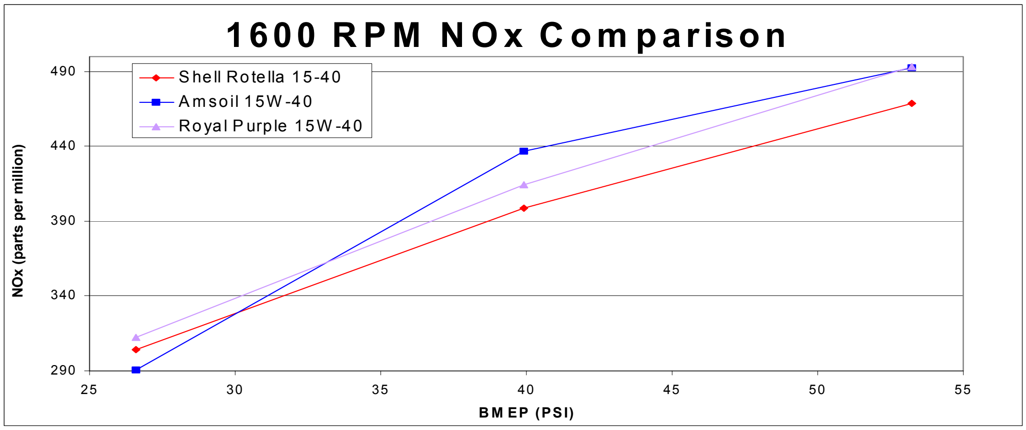


At 1600 RPM, the Royal Purple oil performed better at all loads than the other two oils, again especially at high load. The greatest soot reduction was against Shell Rotella with a decrease in soot generation of 17.58 % at a BMEP of 53.2224 PSI.

3) NO_x Generation Summary

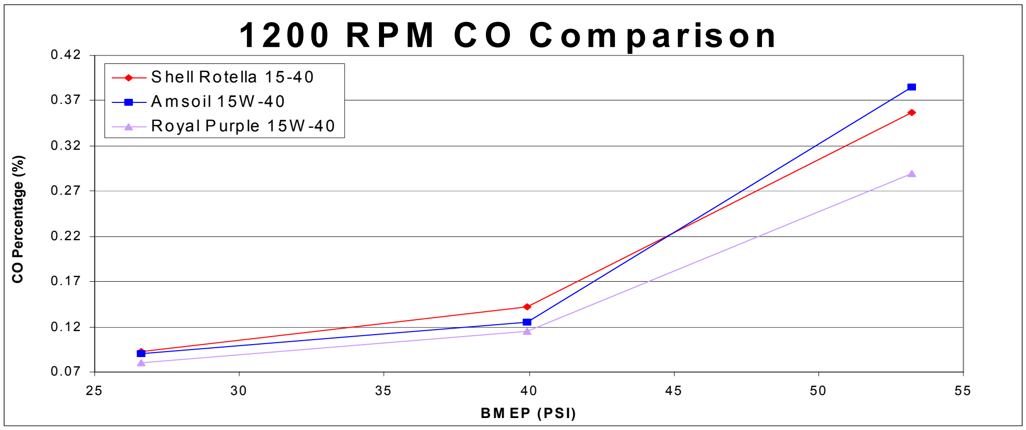


At 1200 RPM, there was a significant reduction in NO_x emissions of the Royal Purple compared to both the Shell and Amsoil lubricants. The highest reduction in NO_x emissions was between Royal Purple and Amsoil, with Royal Purple tests showing an average NO_x production that is 12.06% lower than that of the Amsoil tests.

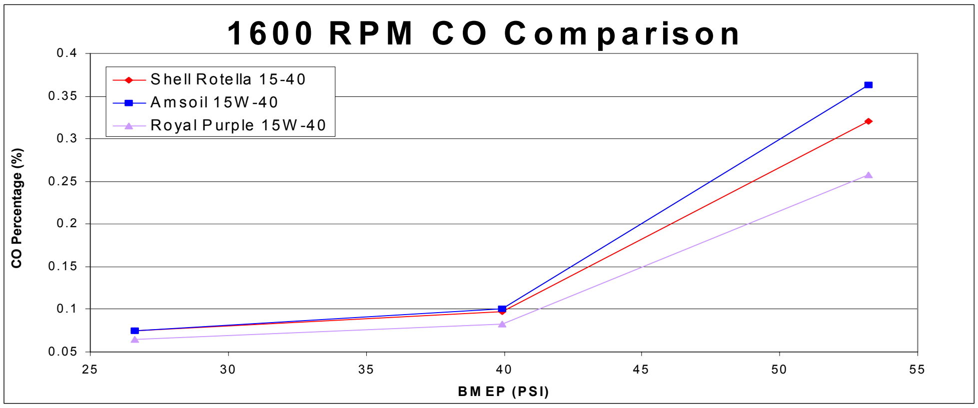


At 1600 RPM, the results are more varied, with Shell Rotella having the lowest NOx levels at high loads. Royal Purple still had lower NOx emissions than Amsoil.

4) CO Generation Summary



At 1200 RPM, the amount of carbon monoxide produced at any load was lowest with the Royal Purple Oil. The greatest reduction was at a BMEP of 53.2224 PSI, which corresponds to a 20lb load. Between Amsoil and Royal Purple, the emissions reduction was 28.15 %.



CO emissions at 1600 RPM were again lowest in the Royal Purple tests. The greatest reduction was over Amsoil with a decrease of 33.87 % in CO emissions.

Soot Level Statistical Analysis Results

*Sequential Sums of Squares **ANOVA** Table*					
Source	**df**	**SS**	**MS**	**F**	**p-val**
Oil	2	14.75180	7.37590	12.69490	0.018524000
Speed	1	21.67450	21.67450	37.30460	0.003637000
Load	2	164.35660	82.17830	141.43910	0.000194410
Oil*Speed	2	0.55517	0.27759	0.47776	0.651540000
Oil*Load	4	12.53290	3.13320	5.39270	0.065755000
Speed*Load	2	20.55020	10.27510	17.68470	0.010323000
Error	4	2.32410	0.58102		

R-square	0.99018
Standard Error	0.76224

The analysis shows that speed, load, and oil tested all had a significant effect on soot production. Load was the factor with the greatest effect, then speed, and finally oil. The three were separated by a factor of ten each. The separation between oils indicated in the means analysis showed that Shell produced the most soot (26.6%), followed by Amsoil (25.17%) and Royal Purple (24.5%) respectively. While this effect was greatly overshadowed by the effect of speed and load, the interaction between oil and soot production is still significant as the p-value is less than .05 (.0185).

Oil Sample Data

		Viscosity	Fuel Dilution	Soot	Oxidation	Nitration	Water %	Antifreeze %
Sample 140138	New Shell	14.4	0	0	0	0	0	0
Sample 140139	New Amsoil	14.8	0	0	0	0	0	0
Sample 140140	New Royal	14.1	0	0	0	0	0	0
Sample 140141	Used Shell	14.9	0	0	0	0	0	0
Sample 140142	Used Amsoil	14.3	0	0	0	0	0	0
Sample 140143	Used Royal	14	0	0	0	0	0	0

Figure 2A - Oil Condition

		Silicon	Iron	Chromium	Aluminum	Copper	Lead	Tin	Nickel	Silv
Sample 140138	New Shell	5	2	0	2	0	0	0	0	
Sample 140139	New Amsoil	3	3	0	2	0	1	0	0	
Sample 140140	New Royal	3	2	0	2	0	1	0	0	
Sample 140141	Used Shell	9	6	0	2	0	3	0	0	
Sample 140142	Used Amsoil	5	5	0	2	0	1	0	0	
Sample 140143	Used Royal	5	4	0	2	0	0	0	0	

Figure 2B - Wear Materials

		Molybdenum	Magnesium	Sodium	Titanium	Boron	Potassium	Calcium	Zinc	Barium	Phosphorus
Sample 140138	New Shell	0	18	5	0	301	10	2573	1316	0	1384
Sample 140139	New Amsoil	0	19	4	0	1	0	3504	1279	0	1328
Sample 140140	New Royal	131	11	3	0	1	4	2531	1116	0	1261
Sample 140141	Used Shell	0	16	5	0	264	8	2182	1125	0	1311
Sample 140142	Used Amsoil	0	16	8	0	7	2	3427	1275	0	1231
Sample 140143	Used Royal	134	9	4	0	1	5	2715	1138	0	1195

Figure 2C - Additive Packages

Oil Sample Analysis

Early engines were often designed to use up engine oil while operating, requiring a continuous input of fresh oil. Most of the oil seeped past the rings and was burned in the engine. This led to the need for frequent oil changes due to the contamination of the remaining oil due to blow-by. In early engines the rule was to change the crankcase oil every 1000 miles. Modern engines have closer tolerances, run hotter and must operate longer between oil changes. Also, they have to operate over large ambient temperature ranges since seasonal oil changes are no longer necessary. Many engine manufacturers now recommend oil changes ever 6000 miles or more.

Modern motor oil is substantially different from the castor oils used in the early years, and now has complex additive packages for maximum performance and minimum wear. These additives include:

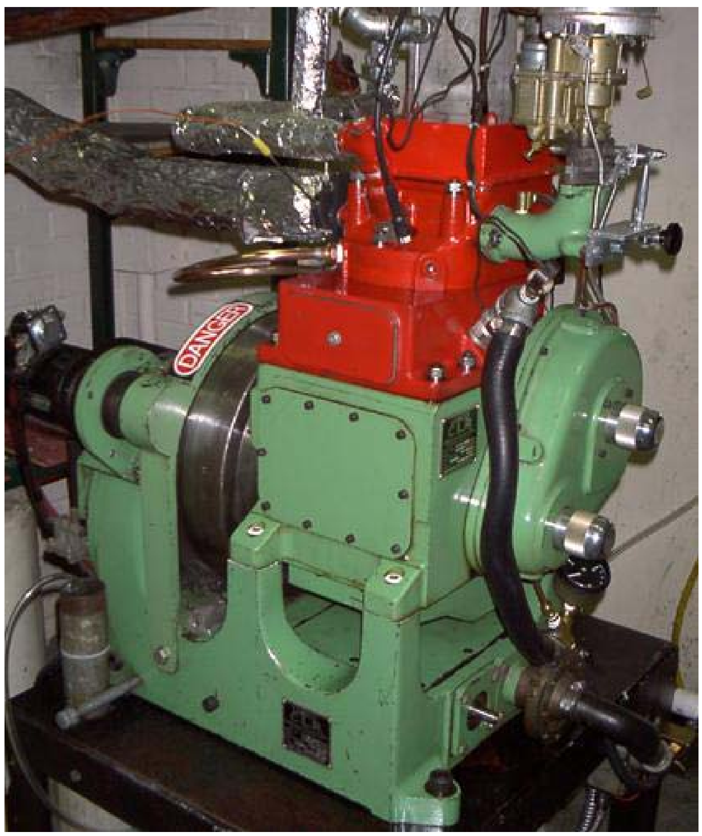
1. Antifoam agents
2. Oxidation inhibitors
3. Pour-point depressant
4. Antirust agents
5. Detergents
6. Antiwear agents
7. Viscosity index improvers

The returned oil samples show that there is decreased wear for all materials for the Royal Purple brand motor oil. As can be seen from the above data, there was no contamination in terms of water, soot or fuel in the oil samples, indicating that the engine stayed well within specifications throughout all testing.

Single Cylinder Gasoline Research Engine Tests

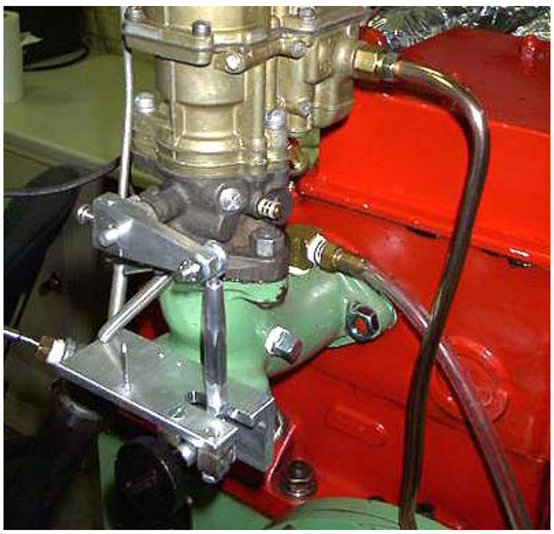
This section documents tests conducted at the North Carolina State University using a CLR gasoline engine designed for oil testing. Shell Formula 5w-30 petroleum based oil, Amsoil 5w-30 synthetic based oil, and Royal Purple synthetic oil with Synerlec additive were tested in the engine under identical conditions. The oils were tested with the engine operating at 1200 rpm and at 1600 rpm. The engine was loaded by means of a brake on the dynamometer, and the throttle was opened until the engine maintained the desired speed. Light engine loads, medium engine loads, and heavy engine loads were simulated at each rpm by adjusting the brake and the throttle valve. Fuel consumption and exhaust gas compositions were recorded at each load.

Research Project Equipment Continued



- Gasoline Engine

The gasoline engine research was performed on a Laboratory Equipment Corp. (Labeco) CLR engine, which is a high speed four stoke designed primarily for oil test and research work. The CLR is a single cylinder engine with a bore and stroke of 3.8125” x 3.750” respectively. The displacement is 42.5 cu. in. and has a compression ratio of 9:1 and was run on 87 octane unleaded gasoline. The oil sump holds between 2-4 pts., and the oil pressure is adjustable. The engine is water-cooled and fuel is metered through a Stomberg carburetor. The throttle adjustment is made through a screw mechanism that is locked for constant RPM research. Before testing began, the engine was completely torn down an rebuilt to “as-new” specifications with a new piston, cylinder sleeve, all new bearings, new valves and new valve oil seals. The engine was then broken in accordance with the LABECO instruction manual before the oil testing started. The carburetor was also completely rebuilt before testing began.



Gasoline Throttle Control Explained

A turnbuckle and lock nut were used to set the engine speed for the gasoline testing. This resulted in very accurate control of engine RPM. There were no variations in the RPMs since two springs were employed to remove any play in the throttle linkage.

Single Cylinder Gasoline Testing Procedure Developed and Used

- Clean out emissions analyzer line with compressed air with analyzer disconnected
- Check engine oil level
- Check accessory case oil level
- Check dynamometer bearing oil level
- Check vacuum pump oil level
- Check that exhaust system valve is turned off
- Replace cotton pre-filters in exhaust measurement system
- Check that the final filter on the emissions tester is not contaminated
- Fill fuel measurement cylinder with 87-octane gasoline

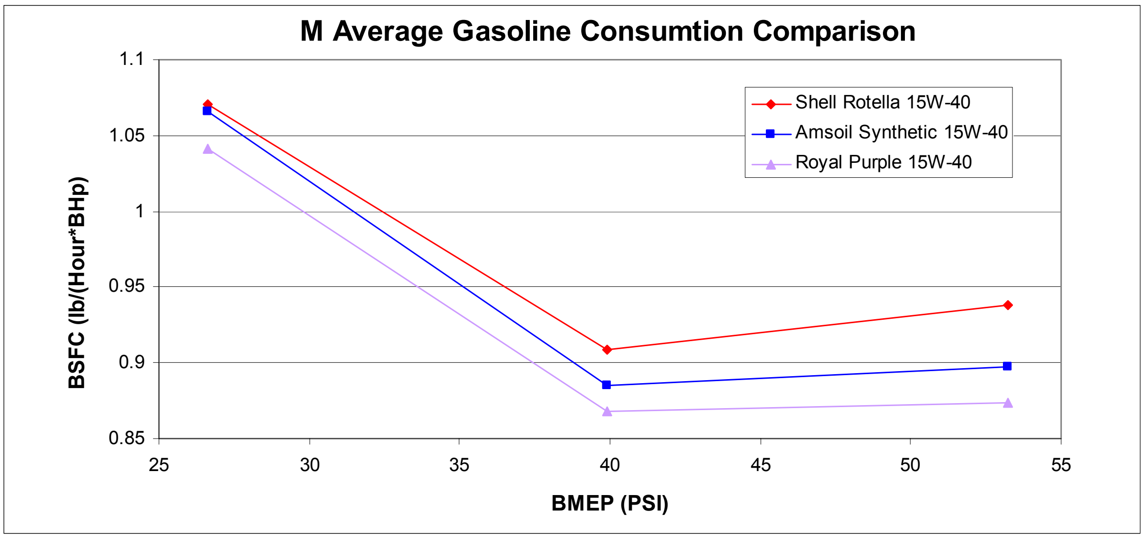
- Turn water supply on, allow pressure to build in expansion tank
- Turn engine exhaust stack fan on
- Check that dynamometer excitation is turned to zero
- Energize all electrical systems, including dynamometer power
- Adjust water level in coolant tower to center mark
- Turn on battery charger
- Turn on crank case vacuum pump, allow vacuum to start building on gage
- Start engine
- Adjust crankcase vacuum for 4 inches water on gage
- Allow to run at no-load for 5 minutes at 600 RPM
- Turn off battery charger
- Over next 25 minutes, gradually increase excitation and engine speed to speed required for testing
- For 30 minutes, run engine at test load and speed to reach steady state
- Check water level in cooling tower
- Make sure that the engine temperature is stable for 5 minutes before beginning testing
- Take emissions and fuel consumption measurements at two different RPM settings and three different loads (we used 1200, 1600 RPM and 10,15 and 20 lb. of load)
- When switching between loads, wait 15 minutes for the engine temperatures to reach steady state
- When switching between RPM's, wait 30 minutes for the engine to reach steady state.
- Fuel Measurement:
- Measure time taken for engine to use 100ml of BP 87-octane regular unleaded gasoline
- Taken with stopwatch between marks on graduated cylinder
- Maintain engine RPM within 10 RPM during test
- Emissions Measurement
- Make sure exhaust system valve is closed
- Disconnect the line at the meter
- Turn emissions meter on, allow meter to complete zero span calibration
- Reconnect line
- Start emissions testing, open exhaust system valve
- Make sure that there is 2.0 SCFH of flow through the meter. If not, a filter is clogged, if too high, adjust with valve
- Maintain engine RPM within 10 RPM of target speed during test
- Meter beeps when test is complete, print out the results
- Close exhaust system valve
- After testing is complete, run engine at no load for 10 minutes to allow to cool down
- Stop engine
- Turn off all electrical devices
- Turn off exhaust stack fan
- Turn off water supply
- Enter data in spreadsheet templates on computer

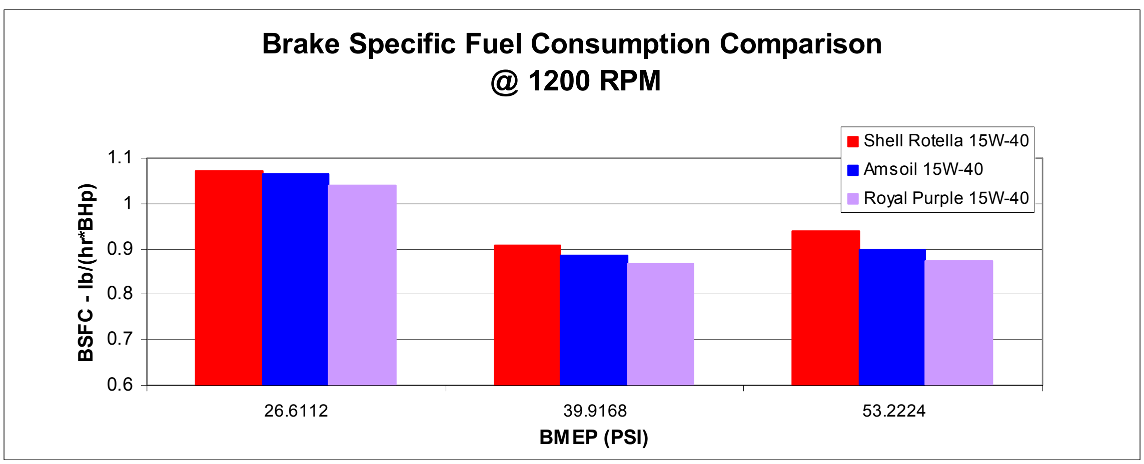
Gasoline Single Cylinder Engine Oil Test Project Results Summary and Discussion

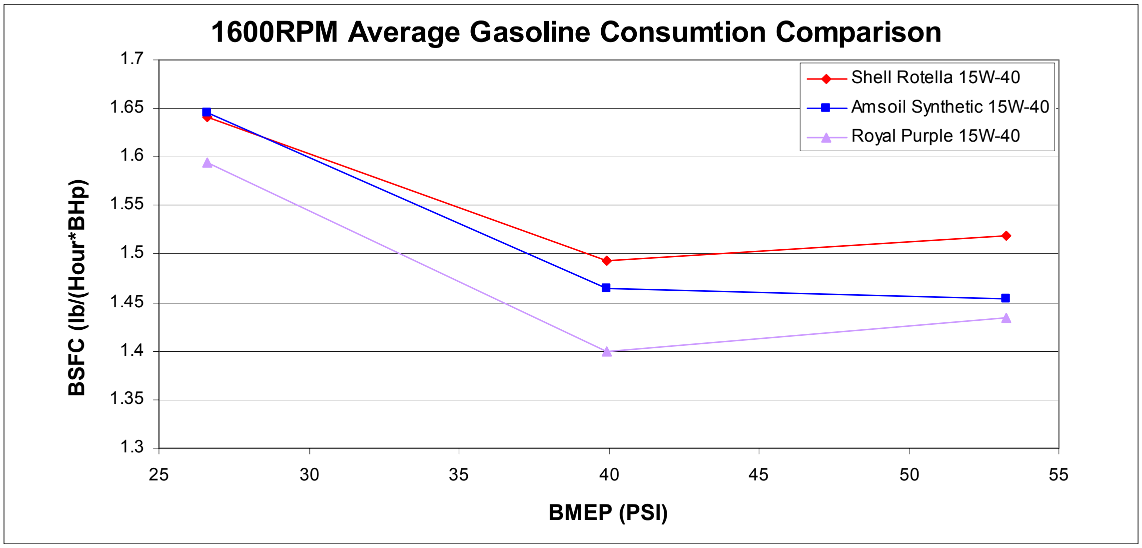
Data Summary for the three oils tested in the Labeco Research Gasoline Engine

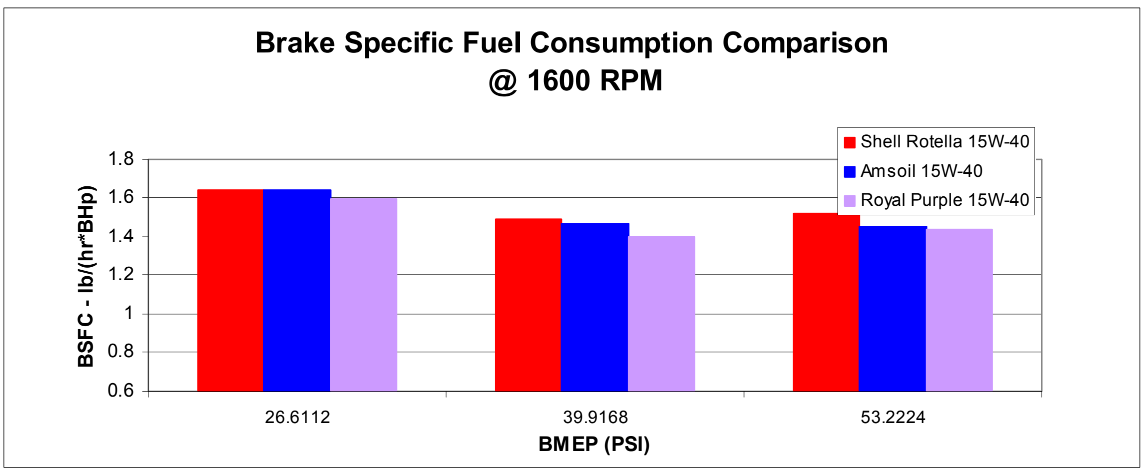
1.) Fuel Consumption Comparison

The experimental data presented in the figures below show that Royal Purple oil required less fuel to satisfy the imposed engine loads than the other two oils at all of the engine loads and engine speeds tested. At 1200 rpm, Royal Purple oil was about 4.5% more fuel efficient than Shell Formula oil, and about 2.5% more efficient than Amsoil. At 1600 rpm the Royal Purple oil required about 5% less fuel than Shell Formula oil, and about 3% less fuel than Amsoil.



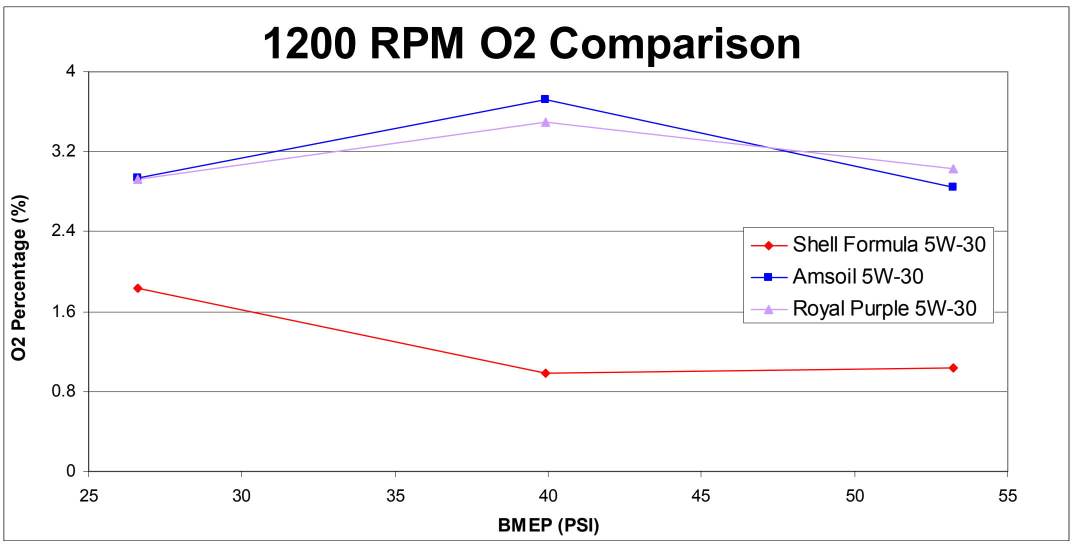


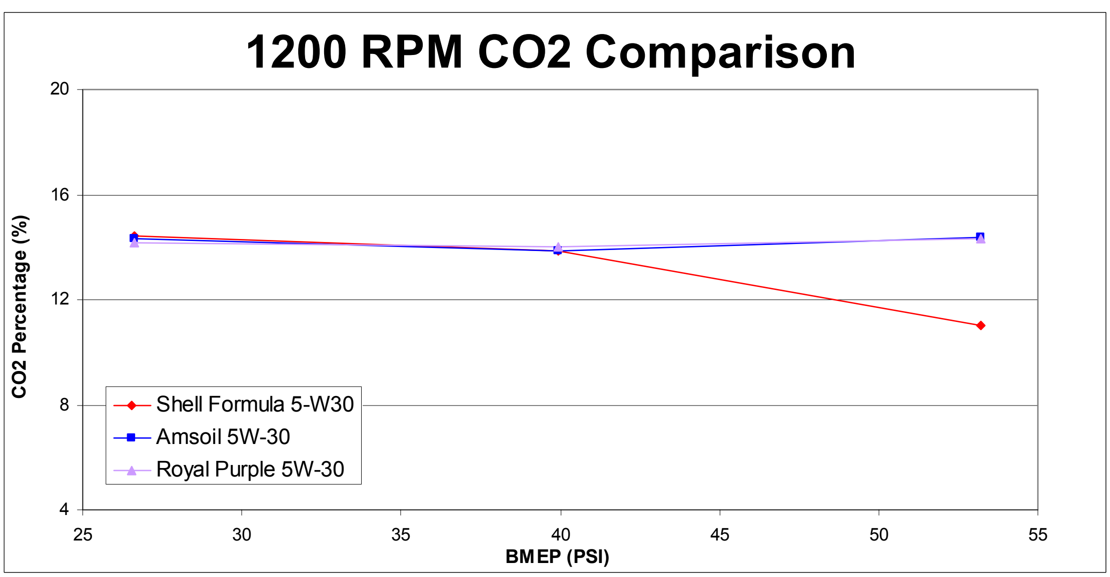




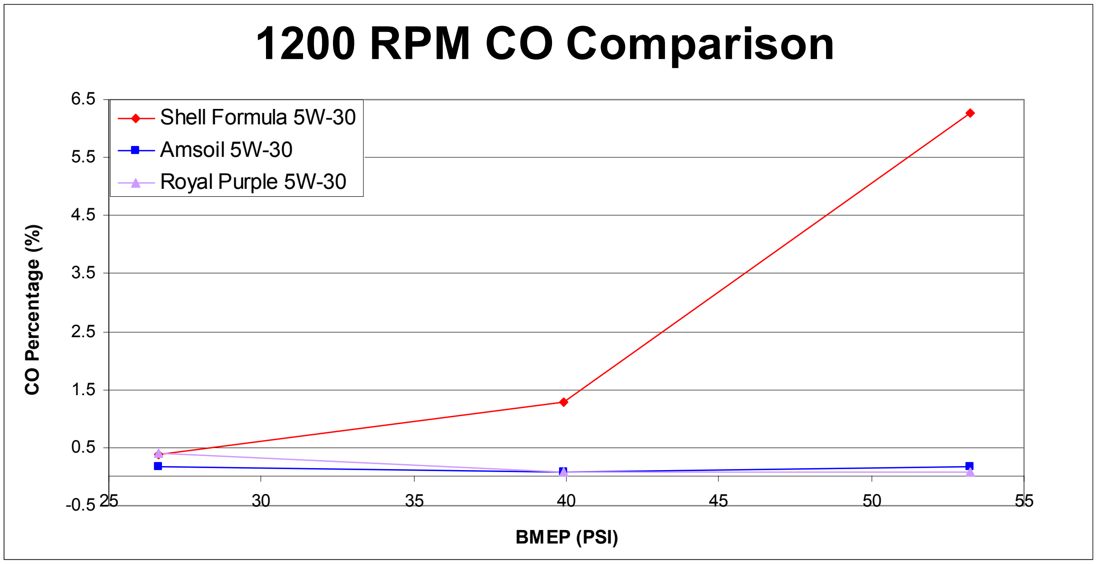
2) Emissions Comparison: Engine exhaust emissions were measured using the Nova Analytical Systems Inc. Autocheck Model 975 Exhaust Emission Analyzer described previously. The analyzer was calibrated before each test using National Welders Research Grade custom gases. The measured Oxygen and Carbon Dioxide levels in the engine exhaust at 1200 rpm are presented in the figures below. The amount of O_2 remaining in the exhaust gases of a gasoline engine depends on the fuel/air ratio, which is regulated by the carburetor. For lean fuel/air mixtures there will not be enough fuel to consume all of the O_2, and the level of O_2 remaining in the exhaust will be high. For rich fuel/air mixtures most of the O_2 will be consumed, and only trace amounts of O_2 will be measured in the exhaust gases. The CO_2 levels also depend directly on the fuel/air ratio. For lean mixtures, there will be excessive amounts of O_2 and N_2 in the exhaust gases, and the percentage of the mixture that is CO_2 will be reduced. The measured O_2 and CO_2 levels for Amsoil and Royal Purple oil are almost identical, as would be expected. The measured Oxygen levels for the Shell Formula oil are slightly lower than those of the other two oils, which would indicate that the carburetor did not maintain the same air-to-

fuel ratio during the test of the Shell oil. The carburetor was not adjusted during the test. Also, the measured CO_2 levels indicate that the air-to-fuel ratio remained constant for every test point (except for the high load point for the shell oil, which is explained below). The O_2 data indicate that the excess air level was about 20% for the Amsoil and Royal Purple oil, and was about 10% for the Shell oil. This difference would tend to make the engine more efficient during the test of the Shell oil. The fuel economy results are actually worse for the Shell oil. All of this indicates that the O_2 data may be in error. The measured O_2 levels could be affected by a small leak that would allow atmospheric air to infiltrate the exhaust gas sample. This would not affect the accuracy of the other data, or the overall conclusions of this work.

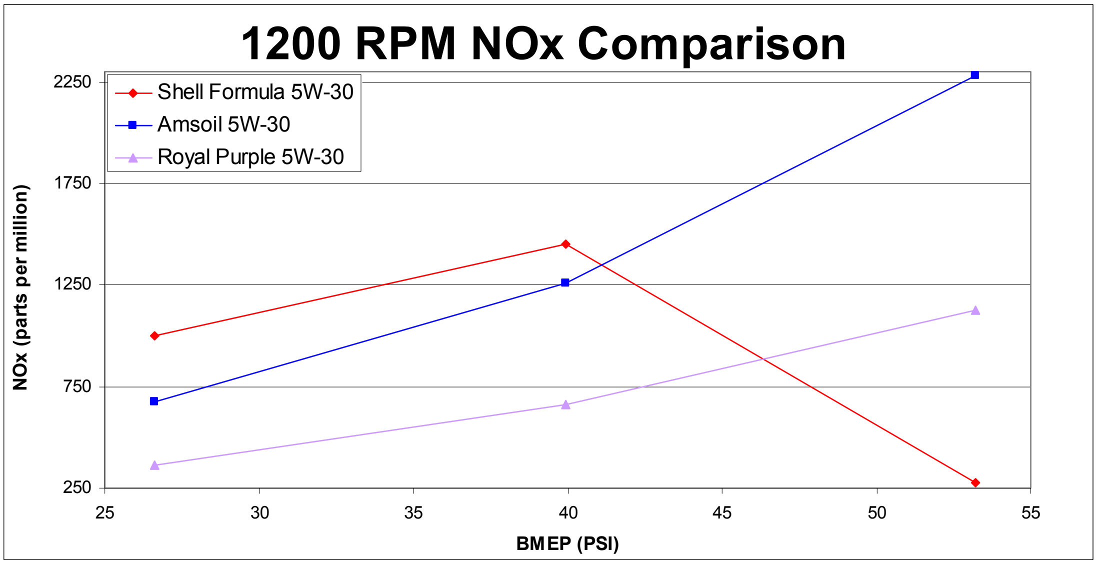




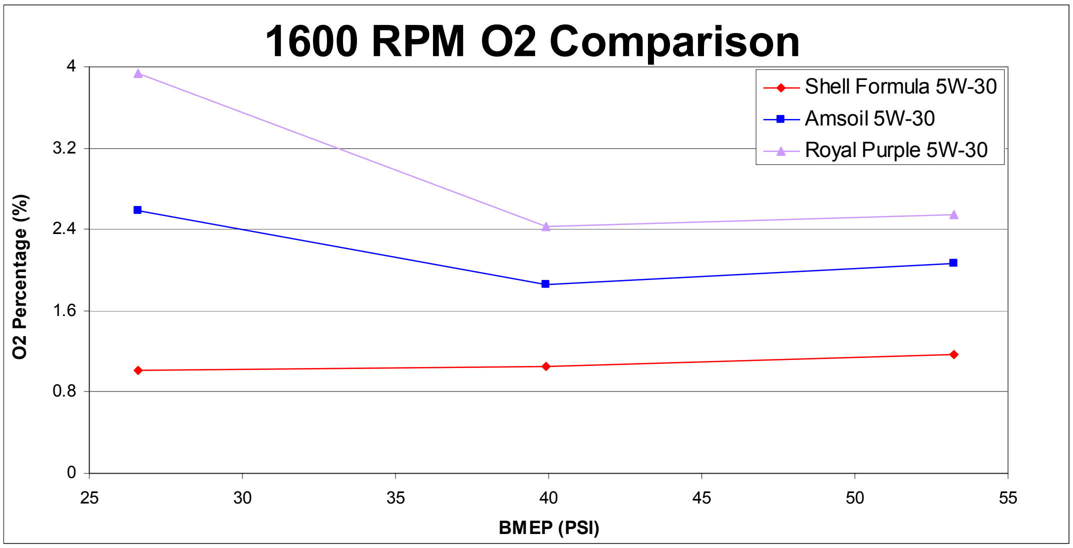
Low Oxygen levels would be consistent with the high levels of Carbon Monoxide measured in the Shell Formula test exhaust and shown in the figure below. The data show that the CO levels in the exhaust of the two synthetic oils were relatively low, and about equal. The CO levels in the exhaust for the mineral oil tests are very high for the high engine load point. The CO_2 level for this point, shown above, is relatively low. This indicates that incomplete combustion occurred with Shell Formula oil when the engine was heavily loaded at l200 rpm. This means that carbon in the fuel was converted to CO instead of CO_2. This is undesirable because of the poisonous gases emitted, and because it reduces fuel economy.



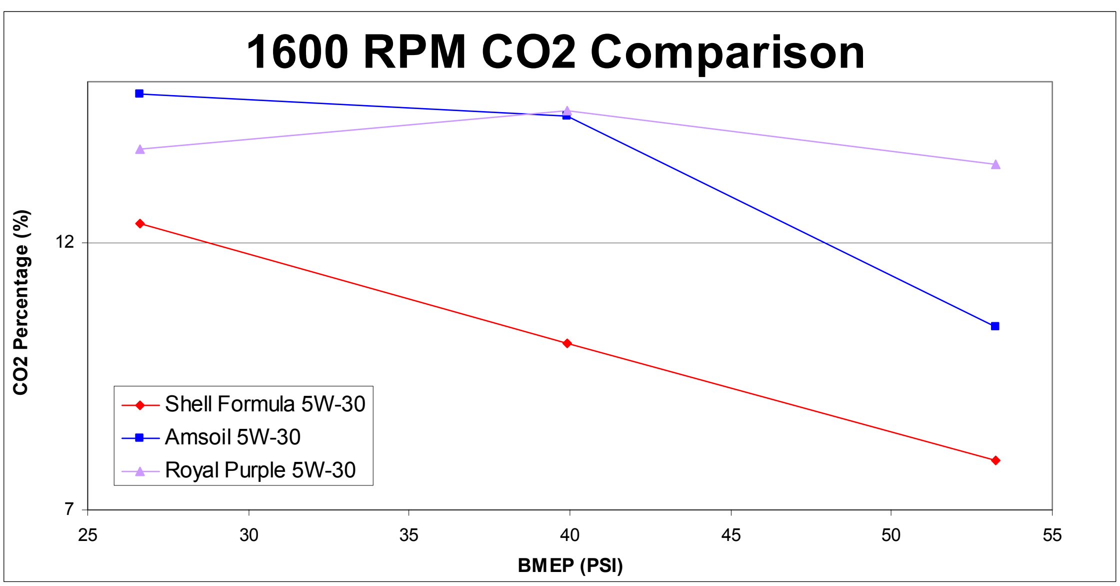
The figure below show that NO_x emissions at 1200 rpm were reduced by more than half when the engine operated with Royal Purple oil. The single exception is for the high load test point for the Shell Formula oil. Undesirable incomplete combustion at this test point is the suspected cause of the low NO_x emission.

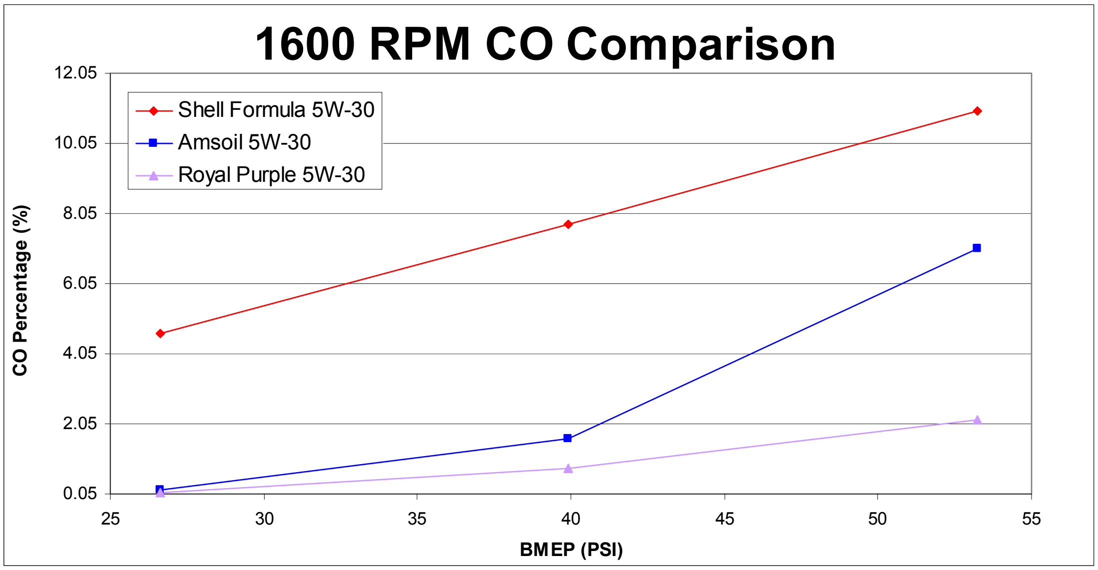


The measured Oxygen levels in the engine exhaust at 1600 rpm are presented in the figure below. The results indicate that excess air was present in the combustion process for every test point. The O_2 data indicates that the fuel/air mixture was leaner during the test of the Royal Purple oil than during the tests of the other two oils. However, the CO_2 data discussed below does not verify this fact. The absolute accuracy of the O_2 data is questionable.

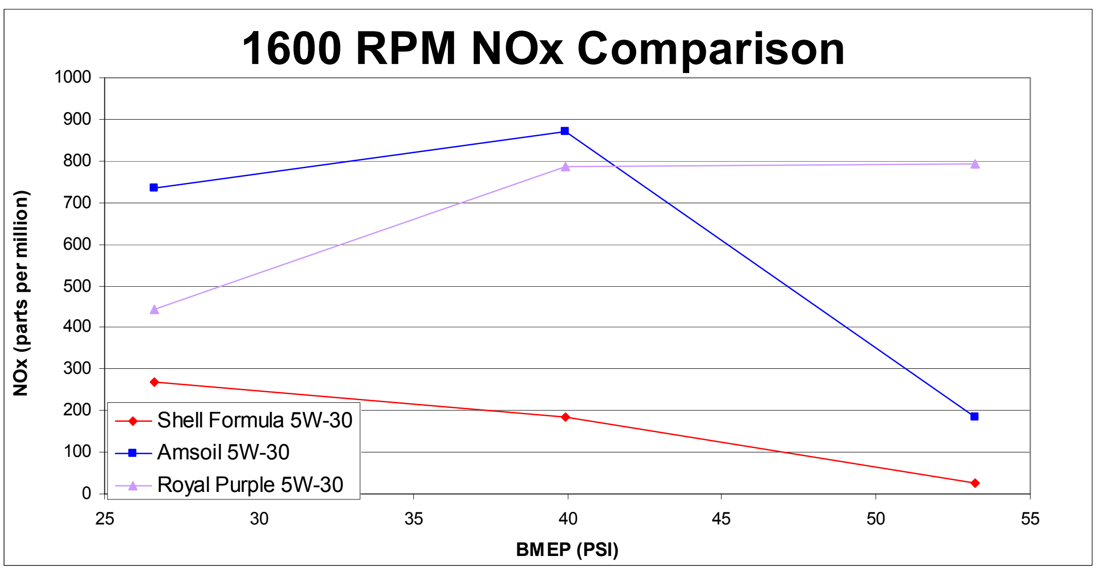


The CO_2 data and CO data presented below indicate that incomplete combustion occurred at all loads at 1600 rpm for Shell Formula oil, and also occurred at high load for Amsoil. Generally, the CO_2 levels decreased when CO was produced by incomplete combustion. The CO levels were relatively low at all loads for Royal Purple oil.





The figure below shows that NO_x levels were lowest when Royal Purple oil was in the engine for every data point at 1600 rpm for which CO levels were acceptable. Overall, the results of the single cylinder tests must be viewed as favorable for the Royal Purple oil. The data shows that the Royal Purple oil improved fuel economy and tended to prevent incomplete combustion. NO_x levels were also reduced by Royal Purple oil when near complete combustion did occur.



Appendix A: CLR Engine Test Definitions

- Blowby: the portion of the combustion reactants and unburned air-fuel mixture which leak into the engine crankcase during operation of the engine
- Rust: the chemical combination of oxygen with ferrous engine components
- Sludge: a deposit principally composed of engine oil and fuel debris, which does not drain from engine parts but can be removed by wiping with a soft cloth
- Varnish: a hard, dry generally lustrous oil insoluble deposit that cannot be removed easily.
- Antifoam Agents: reduce the foaming that would result when the crankshaft and other components rotate at high speed in the crankcase oil sump.
- Oxidation inhibitors: Oxygen is trapped in the oil when foaming occurs and this can lead to corrosion of engine components.
- Detergents: help keep deposits from accumulating, help neutralize acids formed from sulfur contained in the fuel.
- Mass of air = m_a
- Mass flow rate of air = $\dot{m}_a$
- Mass of fuel = m_f
- Mass flow rate of fuel = $\dot{m}_f$
- Engine Power = $\dot{W}$
- Brake work of one revolution = W_d
- Displacement Volume = V_d
- Number of revolutions per cycle = n

Appendix B: CLR Engine Test Formulas

Air- fuel ratio:

AF = ma / mf

Brake Specific Fuel Consumption: $bsfc = \frac{\dot{m}_f}{\dot{W}_b}$

Brake Mean Effective Pressure:

$bmep = \frac{W_b * n}{V_d}$ and $bmep = \frac{4\pi\tau}{V_d}$ for a four-stroke engine

where $\tau = \frac{(bmep)V_d}{2\pi}$

Appendix C ANA-LAB Oil Analysis Test Information

Appendix D Coca-Cola Delivery Truck Oil Analysis Results