SELECT TEST DATA

DurAlt®

Columbia University in the City of New York

Department of Energy · United States of America

Dow

Mercury '1 On The Water

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Harley-Davidson Motor Company

Pfizer

Phillips 66

Total

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pmc

fueling a cleaner world

POLAR MOLECULAR CORPORATION

Select Test Data

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Advanced Fuel Additive Technology for Cost Effective Gasoline Lead Phaseout by Control of Octane Requirement Increase

By

Jerry R. Allsup

Polar Molecular Corporation

For Distribution at the
UN Special Session on Environment and Development
New York, NY
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ABSTRACT

Data shows that a new generation of gasoline additive developed by Polar Molecular Corporation, known as DurAlt Fuel Conditioner (DurAlt FC), controls octane requirement increase (ORI) by inhibiting and reversing the build up of combustion chamber deposits (CCD). The additive can effectively eliminate the use of tetraethyl lead (TEL) which is universally recognized for its harmful health effects, but is still being used in many parts of the world as a gasoline octane enhancer.

ORI is the tendency of a motor vehicle engine to require additional octane ranging from about 5 to 10 octane numbers as the vehicles accumulates 10,000 to 20,000 kilometers. The data shows that DurAlt FC limits the ORI to about 2 octane numbers as compared to the normal increase of 5 to 10 numbers. Thus, the use of this additive can result in reducing the octane demand by 3 or more octane numbers. Typically the use of TEL at 0.15 gram of lead per liter of gasoline increases the octane of fuel by about 3 numbers. Thus in a simple scenario, a country using 0.15 gm/liter of lead could completely eliminate the use of TEL in its gasoline by introducing DurAlt FC additive. The result will be a reduction in the octane value of fuel by about 3 numbers which will be offset by the reduction in octane requirement of the engine by 3 or more numbers.

The use of the additive will not only eliminate or reduce extremely hazardous TEL in gasoline, but also will avoid the need for major and costly refinery modifications to produce high octane components such as benzene and other aromatics which contribute to carcinogenic emissions.

Many countries which use TEL or other harmful octane enhancers, clearly recognize the adverse health implications, but believe they must continue along this path because of the high economic cost of importing unleaded fuel components or building new refinery capability in order to produce high octane unleaded fuel. Economic data is presented that shows the use of DurAlt FC additive is more cost effective than refinery modification and other options.

Introduction

Octane Requirement Increase (ORI) is a phenomenon that occurs in gasoline powered vehicles in which engines experience an increase in the octane requirement as new vehicles accumulate 10,000 or 20,000 kilometers. Typically, the ORI ranges between 5 to 10 octane numbers. The ORI is dependent upon several factors including the vehicle operation mode, fuel composition and engine design. The anticipated ORI and the octane quality of gasoline available in the marketplace are principal elements included in the design of the engine.

Deposits resulting from incomplete combustion inside the combustion chambers of the engine are responsible for the increased octane requirement of the engine. Thus, removing combustion chamber deposits (CCD), or preventing CCD from forming reduces the octane demand of the engine and allows the use of lower octane fuel without adversely affecting the engine performance or incurring engine damage.

A new generation of fuel additive technology is currently available in the marketplace which controls the buildup of CCD and the resultant ORI. Thus the historical assumption that a ORI of up to 10 numbers is unavoidable and must be accommodated by higher octane fuel, is no longer valid. The reduction in octane demand of the engine due to the new fuel additive technology allows the use of lower octane fuel with possible elimination of tetraethyl lead needed to accommodate the historical ORI.

Additives that control ORI are important for future operations that will optimize the new engine octane demand to the octane of the fuel. However, during the transition period while phasing lead out of gasoline, it is desirable that the fuel additives also reduce the octane requirement of the current population of vehicles by reducing the deposits. This is clearly a more difficult performance requirement. Data obtained from large scale fleet operations confirm the ability of the additive to reduce not only the octane requirement increase of new vehicles, but also reduces the octane requirement of used vehicles.

Application of CCD additives - a new way to reduce or eliminate tetraethyl lead

A review of test data generated at a US Department of Energy test facility (National Institute for Petroleum Energy Research) confirm the ORI from normal operations without the DurAlt FC average about 7 octane numbers and the ORI with the additive was only about 2 octane numbers (Ref. 2). Further, the test data show that after the first data point at 2,500 miles, the ORI remained essentially unchanged throughout the rest of the mileage accumulation.

The test procedure involved procuring vehicles with approximately 30,000 miles of normal use and disassembling the engines and removing all deposits before initiating the tests. Mileage accumulation was highly controlled to insure all vehicles received the same operational parameters and included the use of professional drivers and instrumented vehicles. Other test operations including monitoring octane rating of the vehicles were conducted using industry approved test protocols.

FIG. 2 ORI With and Without DurAlt FC Technology
Ford 2.3 liter engine

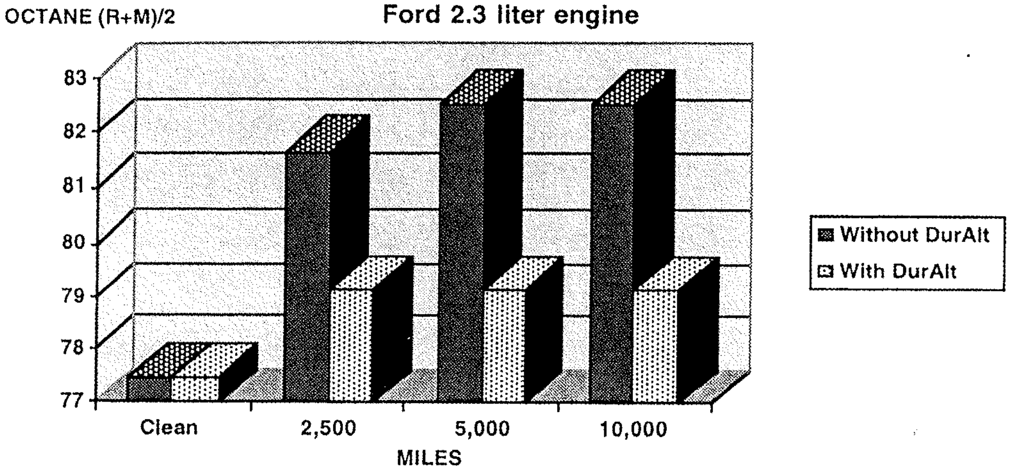
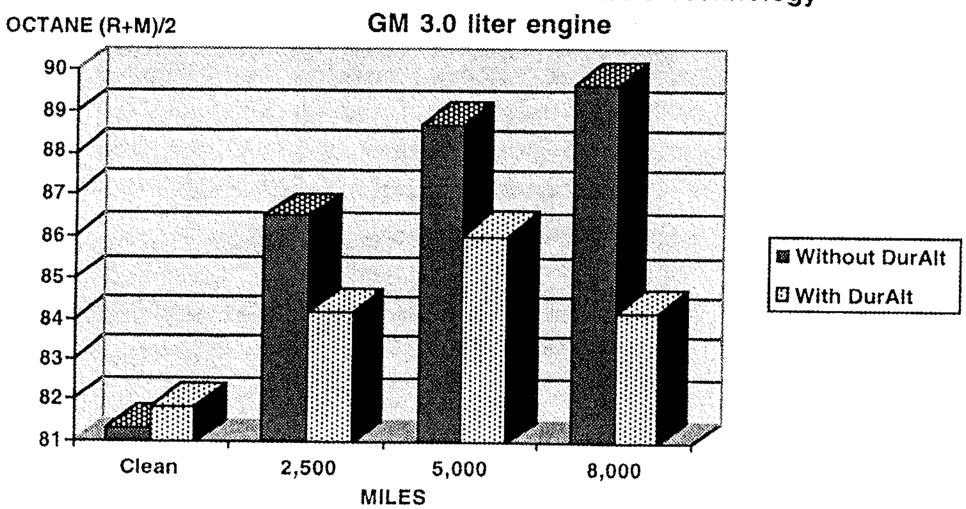


Figure 2 presents data from a fleet of Ford vehicles with 2.3 liter engines showing an ORI of 5 numbers without the additive compared to an ORI of only 2 with the additive. It is also important to note that after the first 2,500 miles the octane requirement remained constant with the DurAlt FC additive, but continued to increase without the additive (Ref. 2).

Figure 3 presents similar data from a fleet of GM vehicles with 3.0 liter engines showing a ORI of 8 numbers without the additive and an ORI of only 2 numbers with the DurAlt FC additive (Ref. 2).

FIG. 3 ORI With and Without DurAlt FC Technology
GM 3.0 liter engine



Technology confirmed in large scale fleet tests

Two public utility companies in the US participated in a large scale fleet test to determine the feasibility of phasing lead from their gasoline and substituting DurAlt FC technology. The vehicles used by both fleets consisted of large trucks with large displacement engines designed for heavy duty operations (Ref. 6).

One of the fleets changed the fuel for their fleet of 34 heavy duty vehicles from the regular leaded fuel 89 octane) to regular unleaded fuel (87 octane). This utility company reported significant engine knocking and related problems. The fleet eventually began using premium unleaded fuel which still did not resolve all of the problems, and finally elected to change back to leaded fuels for satisfactory operation.

The other utility company changed the fuel for their fleet of 139 heavy duty vehicles from the regular leaded fuel to unleaded regular fuel with the DurAlt FC. This fleet reported no problems with knocking and was successful in making the transition from regular octane leaded fuel (89) to the regular grade unleaded fuel (87 octane) with the DurAlt FC, with no related engine problems or driver complaints.

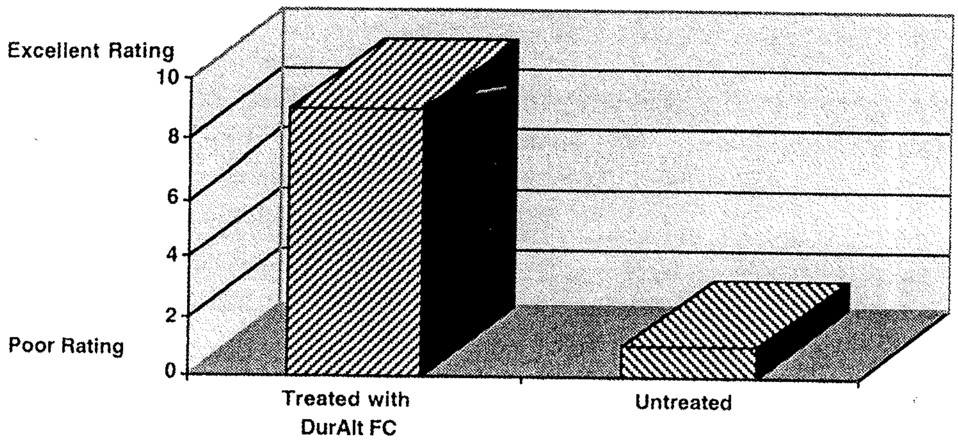
This experience mirrors results from several experiences which document the ORI reduction observed in highly controlled laboratory studies are consistent with the ORI reduction observed in real world fleet tests.

Opportunity in 2 cycle engines

The use of small motorcycles employing 2 cycle engines represents the major mode of motorized transportation in many countries. For example, it is reported that 60 % of the gasoline consumed in India, is used for this transportation sector. The engine technology for these engines typically requires the addition of lubricating oil to the gasoline. In all engines one of the major sources of CCD formation is due to lubricating oil which makes its way by various means into the combustion chamber. Therefore adding lubricating oil directly to the fuel, makes these engines particularly susceptible to the build up of excessive CCD adversely affecting engine life, efficiency and emissions.

Test data published in Mercury Marine advertisements (Ref. 7) confirm the use of the DurAlt FC results in improved cleanliness of the engine combustion chamber using standard industry test methodology and several test engines (Figure 7). Reduction of the CCD in the 2 cycle engine application is particularly significant and confirms the performance of the additive in all engine applications.

Figure 7 Engine Cleanliness Rating (2 cycle engines
(10 = Clean, 0 = Dirty)



National Marine Manufacturers Association (NMMA) Test Protocol
(Tests conducted by Mercury Marine)

Significance of CCD/ORI fuel additive technology

The use of fuel additive technology to control CCD is strongly supported by the automotive manufacturers worldwide. The basic reason is that currently, the engine combustion chamber is not designed to be optimum for a fuel when the engine is new or clean of deposits, but is expected to become "more or less optimized" as the deposits are formed. The deposit formation is influenced by many factors including the engine design, fuel composition, and driving patters, making the task of the engine designer difficult. It would be preferable in the engine designers were allowed to design a specific combustion chamber geometry for a specific fuel when new or clean, and be assured the design would not be perturbed by deposits. The buildup of deposits in a combustion chamber is not a small change, but affects octane requirement by up to 10 octane numbers. When the engine manufacturers are assured that effective technology is in place to control CCD, the engines will be designed for optimum emissions, performance, and economy for a specific fuel throughout the useful life of the vehicle.

Summary and Conclusions

- Technical data generated at several laboratories throughout the world have demonstrated that the DurAlt FC is effective in reducing the normal ORI of engines by about 70% in a wide range of engines, fuels and applications.
- Application of this additive would reduce or eliminate the need for tetraethyl lead in many countries which are currently using about 0.3 gm/liter lead or less.
- The DurAlt FC is demonstrated by independent studies to be the least costly option to reduce or eliminate lead compared to using other high octane blending components or modifying refineries.
- The DurAlt FC has no associated environmental liabilities such as TEL and high aromatic blending components such as benzene. DurAlt FC has received approval by the US EPA for bulk treatment of motor fuels.

The availability of the DurAlt FC technology presents governmental and oil company officials a cost effective option that can eliminate or reduce the lead poisoning of its citizens. Its use is simple and can be implemented immediately.

DURALT® FUEL CONDITIONER

BROAD-SPECTRUM, NON-METALLIC ADDITIVE FOR DIESEL FUELS

ABSTRACT

This report describes the performance of a single, multifunctional fuel additive, DurAlt® Fuel Conditioner, that alleviates many of the common Diesel fuel problems.

Test data obtained from several independent laboratories are presented. The results show that the Additive increased cetane number by an average of 2.5 in a variety of Diesel fuels and reduced hydrocarbon emissions by the order of 20% or more in Diesel Compression-Ignition (CI) engines. Data also show a reduction in particulate and smoke emissions in CI-engines.

The additive improved fuel economy by at least 2-3% - and often much more - in a variety of CI-engines. Further, it reduced both Diesel injector deposits and combustion noise. The Additive also enhances storage stability of Diesel fuels.

Finally, the report suggests that the Additive achieves its multifunctional behavior by modifying the hydrocarbon oxidation (combustion) process in CI-engines.

POLAR MOLECULAR CORPORATION

INTRODUCTION

Compliance with environmentally based mandates requires Diesel engine manufacturers to produce engines that operate efficiently while reducing exhaust emissions. These engine performance constraints are being met by using increasingly sophisticated fuel injection systems, piston/combustion chamber designs, and exhaust system traps. Proper performance of the engine and its control systems requires continual maintenance of these systems. This has placed demands on Diesel fuel quality which are being met by bulk treatment with special purpose detergent, dispersant and cetane improving additives.

Refiners, as a consequence of the gasoline lead phasedown and greater octane requirement of unleaded gasoline, have been experiencing growing difficulty in meeting the demand for increased octane level. This demand has led to: (1) increasingly severe catalytic cracking, which produces more aromatic and olefinic gas oil for Diesel fuel and heating oils, and (2), the expanded use of octane enhancing oxygenates (methyltertiary butyl ether and alcohols) in gasoline.

The quality of both Diesel fuel and heating oil have gradually deteriorated. The use of heavier, higher sulfur crude oils along with more severe catalytic cracking has raised aromatic, olefinic and sulfur contents. The aromatics and olefins have lowered cetane number, while the aromatics and sulfur have increased exhaust particulates and smoke from Diesel (CI) engines, gas turbines and furnaces.

Multiple special-purpose additives are used in Diesel fuel to raise the cetane number, reduce the cloud and pour points, prevent oxidative and bacterial deterioration in storage, and reduce exhaust smoke.

In contrast, DurAlt FC is a patented single, multifunctional concentrate, that can be used in Diesel fuels (including gas turbine fuels and heating oil) to reduce many of the problems mentioned above.

This report presents the results of evaluations by several, independent laboratories. These laboratories are identified and listed in Appendix A. A summary of extensive fleet tests is also included for reference purposes. A mechanism is suggested to explain the multifunctional performance of DurAlt FC in both gasoline and Diesel engines.

DurAlt FC was initially developed because of concern for energy conservation and the control of exhaust emissions. Its main function was intended to improve fuel economy of internal combustion engines without degradation of exhaust emission control. However, it was subsequently observed that it had a cetane improvement effect in CI-engines. This behavior suggested that it might have an important effect in modifying the combustion process and in controlling combustion chamber deposits.

This patented Additive is a several-component mixture of materials containing only carbon, hydrogen and oxygen (*); Patent No. 4,753,661, June 28, 1988. It is a blend of oxygenated aliphatic hydrocarbon liquids, Glycol Ethers, and mixed aromatic and paraffinic fuel solubilizers. The active components are a polar material, compatibilizers for the polar material and hydrocarbons, and a compound for enhancing water tolerance.

Typical physical properties of DurAlt FC are:

Appearance	Clear Amber Liquid
Odor	Sweetish, Distinctive
Specific Gravity at	0.875 @ 60° F
Density	7.33 @ 60°F
Flashpoint (t.c.c)	110° F
Boiling Range	220° - 600° F
Water Content	< 0.5%

COMPRESSION IGNITION ENGINE LABORATORY AND ROAD TESTS

INJECTOR DEPOSITS

Injector coke deposits (nozzle coking) were assessed at Laboratory L-4 by flow testing before and after a 50-hour full-load/maximum speed durability test in a 1.6 liter 4-stroke cycle IDI, CI-engine. Nozzle coking is where deposits accumulate in the tip of the pintle nozzle in an IDI engine. These can cause increased hydrocarbon emissions and increased engine noise, particularly a noticeable "crackle" or irregularity in the combustion. In order to insure consistency of the results, a new set of injector nozzles was used for each test.

Table 1 shows the substantial flow improvement at low injector lifts with 500 ppm and 1000 ppm of DurAlt FC. Low injector lifts correspond to the light loads and relatively low speeds typical of passenger car operation.

TABLE 1

DIESEL INJECTOR FLOW PERFORMANCE

	Percent Flow Loss			Flow Improvement Factor	
		Additive	Additive		
LIFT.mm	Untreated	500 ppm(m)	1000 ppm(m)	500 ppm(m)	1000 ppm(m)
0.05	90.79	72.42	65.25	2.99	3.77
0.1	90.52	70.46	61.48	3.12	4.06
0.2	86.10	66.64	54.08	2.40	3.30
0.3	75.40	56.94	49.55	1.75	2.05
0.4	59.60	44.09	47.49	1.38	1.30
0.5	38.64	23.16	35.96	1.25	1.04
0.6	20.86	20.79	24.58	1.00	0.95
0.7	14.21	14.71	18.53	0.99	0.95
0.8	5.82	5.89	8.67	1.00	0.97

ENGINE EMISSIONS

CI-engine emissions were determined for two engines on test stands. The first engine was a 4-cylinder, 1.6 liter four-stroke cycle IDI engine in Laboratory L-4. It was tested using a simulated ECE-15 procedure. The fuel was a European, consumer-type, low sulfur fuel. For both the untreated and treated fuel, emission tests were run after a 1-hour break-in following a combustion chamber cleaning and replacement of injectors and valve seats.

The second engine was a four-cylinder, 4.7 liter (281 in^3) 2-stroke cycle DI engine in Laboratory L-3. It was tested using the SAE J1003, 13-mode test cycle. D-2 Reference Fuel was used untreated for the initial testing after installation of new injectors. Twenty hours of running then was accumulated using DurAlt FC treated D-2 Reference Fuel. The 20-hour accumulation cycle consisted of 5 minutes of idle, 40 minutes of 50% load at 26.7Hz (1,600 rpm), 40 minutes of 90% load at 35Hz (2,100 rpm), and 35 minutes of 25% load at 35Hz (2,100 rpm).

Results from both laboratories are described in Appendix C, Table C-1 and C-2. Table 3 shows that the Additive substantially reduced hydrocarbon emissions and either particulate matter or smoke. The absence of particulate reduction in the 4.7L 2-stroke engine probably reflects 1) the fact that a majority of the 2-stroke particulate matter emissions come from oil consumption and 2) the test procedure. The procedure at Laboratory L-3 did not test the untreated fuel after accumulation of injector deposits.

TABLE 3

PERCENT REDUCTION IN COMPRESSION IGNITION EXHAUST EMISSIONS

	Lab L-4		Lab L-3		
TEST PROCEDURE	1.6 L, 4-Stroke IDI ECE-15 SIMULATION		4.7 L, 2-Stroke DI 13-MODE		
			OVERALL	MAX TORQUE SPEED	MAX LOAD RATED SPEED
Treatment, ppm	500(m)	1000(m)	667(v)	667 (v)	667(v)
NO_x	7 *	-6 *	-7 *	-5 *	-9 *
Particulates	22	39	-3 *	11*	-14 *
Smoke	--	--	--	61	25
HC	13	43	22	23	17
CO	6	22	17	10	27
BSFC	2.6	2.8	0	0	0

FUEL ECONOMY

Fuel economy improvements using DurAlt FC in CI-engines are shown in Figure 1. Results for identifications 1 through 5 are from dynamometer tests using engines reconditioned prior to testing. Test identifications 6 through 12 are from road or field tests.

The data for test identification 1 was obtained with the simulated ECE-15 cycle, the official European legislative procedure used for emission evaluations. This engine was the only indirect injection type in the group. All of the identifications are listed in Appendix B. The majority of the additive concentrations for these 11 tests were about 1000 ppm(v).

Results, as with SI-engine fuel economy, vary over a considerable range. However, for the CI-engines there does not appear to be any correlation of the magnitude of the improvement with the engine's previous condition.

CETANE NUMBER

The additive improves the ASTM D-613 cetane number of CI fuels. The test uses a CFR engine. Table 4 shows cetane number increases ranging to a maximum of about 5 CN at a 1000 ppm treatment level.

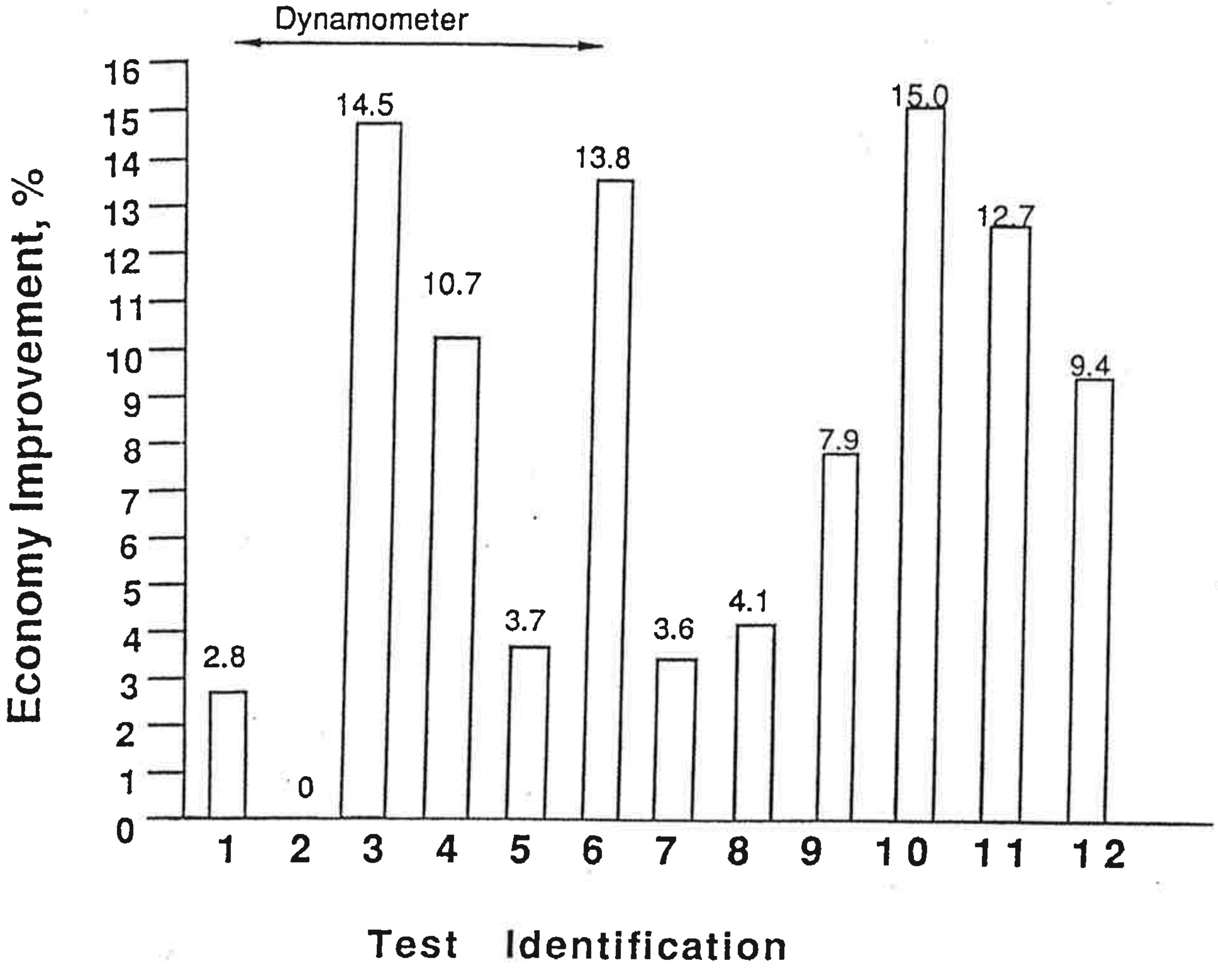
TABLE 4

CETANE NUMBER IMPROVEMENT
ASTM D-613
(average change)

	Untreated		Treated Fuel									
Fuel	Fuel		500 ppm			1000 ppm			2000 ppm			Lab
LC	37.0	37.0	37.3	37.5	(0.4)	39.0	38.7	(1.9)	39.0	38.7	(1.9)	L2
D2-1	42.2	42.3	45.1	45.4	(3.0)	46.3	46.4	(4.1)	--	--	--	L2
D2-2	44.9	--	--	--	--	46.8		(1.9)	--	--		L2
PRE	45.0	45.0	--	--		49.6	50.3	(5.0)	50.1	47.2	(3.7)	L2
2D	46.1	48.2	--	--	--	46.6	46.6	(-0.7)	47.1	47.6	(0.2)	L2
LS	52.7					55.2		(2.5)				L4*
Mean Increase					(1.7)			(2.5)			(1.9)	

Figure 1

Fuel Economy Improvement With The Additive, C. I. Engines



SUMMARY OF FLEET EXPERIENCES

Fuel economy data obtained in the earlier period of Additive development convinced two fleet operators to run their own extensive tests. These tests, now extending over several years, confirmed the economic value of DurAlt FC. The experience gained from these fleet tests, although qualitative and not subject to statistical analysis, did provide information on other aspects of the performance of the Additive. These have subsequently been confirmed by controlled laboratory and road tests. Many of these tests are continuing.

UTILITY AND INDUSTRIAL PLANT FLEETS

This is a very brief summary of the experiences of a specific electric utility gathered over several years while operating some 654 vehicles ranging from passenger cars to large Diesel trucks. The voluminous records, obtained by the operating department, are on file and available. As of late 1990, the utility fleet has treated over 3,000,000 gallons of gasoline.

Generally, the utility vehicle fleet spends a major fraction of the time idling. This is interspersed, with runs of about one hour at interstate highway speeds. Such operation is conducive to the development of combustion chamber deposits with consequent knocking and burning of exhaust valves. Introduction of DurAlt FC eliminated valve burning problems within a year and also essentially eliminated reports of knocking and pinging.

MANUFACTURING FLEET

This fleet consists of approximately 1200 vehicles, including about 1000 gasoline-powered cars and light trucks. The remainder consists of Diesel-powered heavy trucks and construction equipment. The fleet operators primarily within the confines of a large industrial plant, hence almost all operation is at low speed.

About five years ago, by using DurAlt FC, this company was able to change their gasoline fuel from 89 (R+M)/2 leaded gasoline to 87 (R+M)/2 unleaded gasoline. A fuel economy improvement was recorded and no problems with knocking/surface ignition or exhaust valve recession were observed.

STATIONARY GAS TURBINES

Evaluations were conducted on two utility-owned gas turbines to assess improvements in fuel economy between the normal, untreated base fuel, the fuel treated with an iron-based additive, and fuel treated with DurAlt FC. Fuel consumption data in gallons per Megawatt hour were obtained using a standard OEM monitoring procedure.

Use of DurAlt FC yielded a 1.1% reduction in fuel consumption compared with untreated fuel and a 3.6% reduction compared with fuel treated with the iron-based additive. Additional fuel stabilization benefits were reported.

ADDITIVE CONCENTRATION

The DurAlt FC concentrations in the fuel used in these many tests has not been a fixed quantity. The range of additive concentrations used has ranged from 500 to 2000 ppm. The wider range of concentrations are more typical of recent tests exploring the possibility of optimum performance. Earlier testing was usually performed using only one concentration. For example, the Electric Utility fleet used 556 ppm while the stationary gas turbine testing was conducted at 667 ppm.

Laboratory L-2 evaluated cetane number improvement for Diesel fuel. An optimum concentration was indicated at about 1000 ppm. This concentration also provided appreciable Diesel fuel storage stability improvement.

CONCLUSIONS

The results reported show that our new Additive technology successfully treats a broad spectrum of important middle distillate fuel-related problems.

In Diesel fuel DurAlt Fuel Conditioner:

1. Reduces injector coking.
2. Reduces engine noise.
3. Reduces exhaust hydrocarbons, carbon monoxide, and particulates/smoke emissions.
4. Reduces fuel consumption.
5. Increases cetane number.
6. Improves fuel stability in storage.

A hypothesis that DurAlt FC primarily functions by affecting hydrocarbon oxidation processes appears consistent with actual performance.

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A Broad-Spectrum, Non-Metallic Additive for Gasoline and Diesel Fuels: Performance in Gasoline Engines

O. L. Nelson, Jr. and J. E. Larson
Polar Molecular Corp.

R. S. Fein, D. D. Fuller and G. K. Rightmire
Scientific Advisor to Polar Molecular Corp.

R. W. Krumm and G. E. Ducker
Pfizer, Inc.

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and Exposition
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ABSTRACT

This paper describes the performance of a single, multifunctional additive that alleviates many of the common gasoline and Diesel fuel problems. The additive has been deemed "substantially similar" by the EPA and thus may be used for bulk treatment of unleaded gasoline.

Test data obtained from several independent laboratories are presented. The results show that the additive limits octane requirement increase (ORI) to an average of about 30% of that experienced when using untreated gasolines; reduces hydrocarbon emissions by the order of 10% or more; improves fuel economy approximately 1.5% - and often much more - in a variety of engines; and also reduces exhaust valve recession and combustion chamber deposits.

The additive effects on Diesel engine performance and on combustion modification in both gasoline and Diesel engines will be reported later.

RECENT DEMANDS ON ENGINE PERFORMANCE AND FUELS

Compliance with environmentally based mandates has forced automobile manufacturers to produce spark-ignition (SI) engines that operate reliably with curtailed evaporative and exhaust emissions and improved fuel economy while using unleaded gasoline.

These engine performance constraints have been met by using increasingly sophisticated induction, piston/combustion-chamber, exhaust, and control systems. Maintenance and performance of these systems has placed demands on gasoline quality which are being met by bulk treatment with special purpose, detergent and dispersant additives, and by using higher octane gasoline.

Detergent and dispersant additives quite effectively deal with induction system deposits, but have not been very effective in preventing Octane Requirement Increase (ORI), presumably from combustion chamber deposits associated with extended use.

Refiners, as a consequence of lead phasedown and greater octane requirement of unleaded gasoline, have been experiencing growing difficulty in meeting the demand for increased octane levels. This demand has led to: (1) increasingly severe catalytic cracking, and (2), the expanded use of octane enhancing oxygenates (methyl t-butyl ether and alcohols) in gasoline.

Heavier, higher sulfur crude oils along with the more severe catalytic cracking have raised aromatic, olefinic and sulfur contents. Consequently, the quality of both Diesel fuel and heating oil has gradually deteriorated. The aromatics and olefins have lowered cetane number and the aromatics and sulfur have increased exhaust particulates and smoke from Diesel (CI) engines, gas turbines and furnaces.

Several single-purpose additives have been used in Diesel fuel to raise the cetane number, reduce the cloud and pour points, prevent oxidative and bacterial deterioration in storage, and reduce exhaust smoke.

In contrast, the additive described in this paper is a single, multifunctional concentrate, for use in both gasoline and Diesel fuels (including gas turbine fuels and heating oil) to reduce many of the problems mentioned above.

The paper presents the results of SI-engine evaluations by several, independent laboratories, identified in Appendix A.

Topics addressed are ORI, passenger car exhaust emissions, fuel economy, octane number and octane related engine performance, and valve seat recession. Results showing that the additive affects CI-engine injector deposits, engine combustion noise, exhaust emissions, fuel economy, cetane number, cold fuel flow, and fuel storage stability will be published subsequently.

A summary of several fleet tests is also included at the end of the paper as evidence of acceptable field performance.

ADDITIVE HISTORY — The additive discussed in this paper was initially developed to improve fuel economy of internal combustion engines without degradation of exhaust emission control systems. It was subsequently observed that the additive had a knock-reduction effect in SI-engines and a cetane improvement effect in CI-engines, and reduced hydrocarbon and smoke emissions. This behavior suggested that the additive might have an important effect in modifying the combustion process and in controlling combustion chamber deposits.

ADDITIVE DESCRIPTION — The additive is a several-component mixture of materials containing only carbon, hydrogen and oxygen; U.S. Patent No. 4,753,661, June 28, 1988. It is a blend of oxygenated aliphatic hydrocarbon liquids, glycol ethers, and hydrocarbon fuel solubilizers. The active components are a polar material, compatibilizers for the polar material and hydrocarbons, and a compound for enhancing the water tolerance of the additive.

SPARK-IGNITION ENGINE LABORATORY AND ROAD TESTS

OCTANE REQUIREMENT INCREASE — Octane requirement increase is observed with extended operation of gasoline engines. In order to maintain normal engine performance, under these conditions, a higher octane fuel is often required. Although a number of factors may be involved in the phenomenon of ORI, combustion chamber deposits are recognized as being a major contributor to the problem. The effect of the additive on ORI was determined by Laboratories L-3, L-4, and L-6 using three different test procedures and five engine/base fuel combinations.

10 Car Road Test — Laboratory L-3 tested six 1985 cars manufactured by Company A and four 1984 cars manufactured by Company B. The Group A cars were equipped with 3.0 liter V-6 port-injected engines and automatic transmissions; the Group B cars were equipped with 2.3 liter 4-cylinder carburetted engines and automatic transmissions. Cars within Group A consisted of three each of two body styles of the same size. All cars in Group B had the same body style.

In preparation for testing, the cylinder heads of each of the cars were removed and the combustion chambers cleaned. The valve train assembly (especially the valve guide clearances) were inspected to insure that undue amounts of lubricating oil would not enter the combustion area and thus affect the test results. Crankcase oil was changed and oil, air and fuel filters were replaced, together with spark plugs, EGR and PCV valves. Each of the engines was then tuned to manufacturer's specifications.

The gas tanks were drained and filled with a commercially available unleaded regular fuel obtained from a single batch. The cars were then driven for approximately 100 miles, under identical conditions in an attempt to equalize combustion chamber deposits. At this point, octane requirement evaluations were made with a chassis dynamometer, using the CRC designated E-15-87 test procedure. The initial octane requirements for each of the ten cars was thus established.

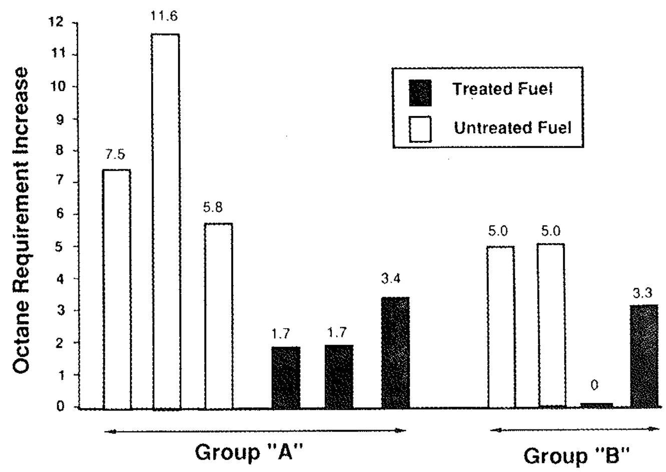
Fuel for half of each of the Group A and B cars was treated with the additive at a concentration level of 667 ppm. A closed route representing both city and country driving conditions was followed with all of the vehicles traveling in line. The 100-mile route was traversed at an average speed of about 64 km/hr (40 mph), with the maximum speed limited to 97 km/hr (60 mph). Vehicle order in the line and vehicle-driver combinations were rotated.

Octane requirement levels were determined for each of the cars after 2,500 and 5,000 miles. Based on the trends of the results, the Group A cars were subsequently run to 8,000 miles. The Group A car tests were then terminated, since the laboratory judged that the octane requirements had essentially stabilized.

The octane requirements among the Group B vehicles were smaller than the Group A vehicles. Therefore, Group B test duration was extended to 10,000 miles to assure that equilibrium had been attained. The octane requirement results are shown in Table 1 and the ORI's are summarized in Figure 1. Mean ORI with the additive treated fuel was 6.0 octane numbers lower than with untreated fuel for Group A cars and 3.3. lower with Group B cars.

Figure 1

Octane Requirement Increase Over Test Duration (R+M)/2



1.6 L Engine Test — An additional ORI evaluation was made by Laboratory L-4, with a European 1.6 L, 4-cylinder, crossflow 4-stroke engine with a compression ratio of 9:1. The twin choke carburetor was modified to permit air/fuel ratio adjustment by control of float chamber pressure.

The engine was initially run-in for 20 hours over a range of speeds and loads. The test schedule in this case took the form of a 200 hour mixed-cycle run, with octane requirement, part-load exhaust emissions and fuel consumption being determined at 50 hour intervals. Octane requirement was determined from the spark advance producing borderline knock. The cycle used in this test program is listed in Table 2. It is representative of a typical European engine duty cycle.

The 200 hour test was completed twice, first with the baseline fuel and then with 424 ppm of the additive. Prior to each test the engine was stripped, cleaned and measured.

The initial octane requirement of the engine at the start of the baseline fuel test was 93.5 RON. After the 200 hour run, this increased by 2.8 to 96.3, as shown in Figure 2.

After rebuilding the engine, the initial octane requirement was 94 instead of 93.5. After the 200 hour run, the octane requirement with the additive, had increased by 1.2 to 95.2. Thus, ORI with the additive was reduced 1.6 RON from that for the baseline gasoline, or a 57% reduction in ORI requirement.

TABLE 1
OCTANE REQUIREMENT
(R + M)/2

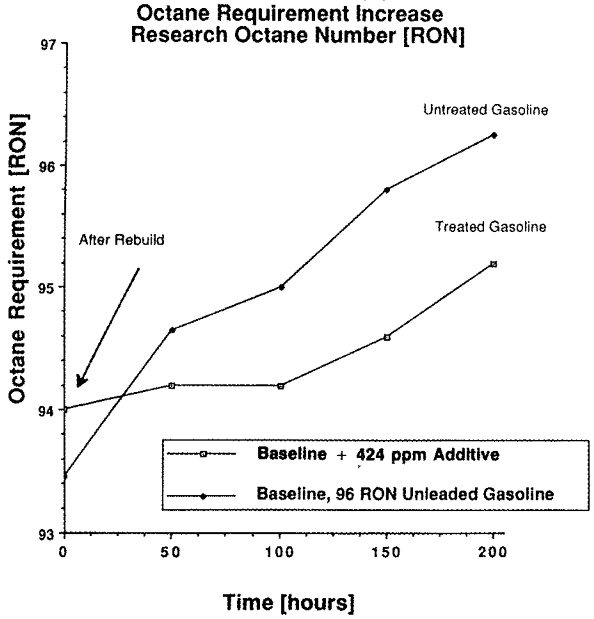
Group A Car No.	Concn. ppm	MILES ACCUMULATED 0	2500	5000	8000	10,000	FINAL ORI
1	0	80.8	87	87	88.3	-	7.5
2	0	80.8	84.2	90.8	92.4	-	11.6
4	0	82.5	88.3	88.3	88.3	-	5.8
3	667	82.5	84.2	84.2	84.2	-	1.7
5	667	82.5	84.2	87*	84.2	-	1.7
6	667	80.8	84.2	87*	84.2	-	3.4
Group B							
8	0	77.5	82.5	82.5	-	82.5	5.0
10	0	77.5	80.8	82.5	-	82.5	5.0
7	667	77.5	77.5	77.5	-	77.5	0
9	667	77.5	80.8	80.8	-	80.8	3.3

* Erroneous data because of procedural problems discovered after testing

TABLE 2
TEST SCHEDULE
1.6 L, 4-Cylinder Engine

Condition	Engine Speed rev/min	Engine Load BMEP	Time Minutes
1	2400	2.5 bar	20
2	3600	4 bar	20
3	3000	Full Load	5
4	2400	5.5 bar	20
5	1200	5.5 bar	20
6	1200	1.5 bar	20
7	850	Idle	15

Figure 2
Fuel Additive Tests
Octane Requirement Increase
Research Octane Number [RON]



10,000 km Road Tests — Laboratory L-6, a major European petroleum company, also ran some extended road tests on a car equipped with a 4-cylinder gasoline engine. These were four, 10,000 km tests run in series with a different fuel in each test. The combustion chamber was cleaned between tests. Octane requirement for each cylinder was determined from the spark advance producing borderline knock. The knock and octane requirement characteristics of this engine were very well known to this laboratory. Based on this experience, the ORI reductions by the additive that are shown in Table 3 were "considered to be very significant".

TABLE 3
OCTANE REQUIREMENT INCREASE*

	Untreated	Treated	ORI Reduction	Percent Reduction
Leaded Gas	4.6	0.8	3.8	82%
Unleaded Gas	1.5	0.3	1.2	80%

* Average Values of the 4-cylinders

GASOLINE ENGINE EMISSIONS — FTP Tests — Laboratory L-1 tested two pairs of 1986 cars using the 1975 Federal Test Procedure. Appendix B describes the work, summarizes the results and the statistical analyses. Table 4 presents the hydrocarbon and fuel economy results analyzed in terms of percent improvement when using the additive. Results are shown for the full three-bag FTP tests and for the hot transient (HT) third bag portion of the test.

Table 4 shows that additive use consistently reduces hydrocarbon emissions and increases fuel economy by the order of 5-15% and 1.5-2.5%, respectively. Results in Appendix B Table B-2 show that carbon monoxide and NOx emissions are not consistently nor, in most cases, significantly affected by additive use.

TABLE 4
EFFECT OF ADDITIVE ON
HYDROCARBON EMISSIONS AND FUEL ECONOMY
Two Car Pairs, 3 Replicates, 333 ppm**

HYDROCARBON EMISSIONS

	Percent Reduction from Untreated		
Additive Use	0 mi	500 mi	1000 mi
FTP			
Car Pair C		13.7 #	
Car Pair D	5.2 &	3.2	4.6
HT			
Car Pair C		16.1 #	
Car Pair D	10.0 @	11.4 #	14.3 &

FUEL ECONOMY
Carbon Balance

	Percent Increase from Untreated		
Additive Use	0 mi	500 mi	1000 mi
FTP			
Car Pair C		2.0 #	
Car Pair D	-0.1	1.5 #	1.4 #
HT			
Car Pair C		2.4 #	
Car Pair D	0.1	1.5 #	1.7 *

# $p < .01$ by two tail t-test
* $p < .05$ by two tail t-test
@ $p < .1$ by two tail t-test
& $p < .2$ by two tail t-test

**500 ppm used in one Pair D car after 500 miles FTP testing

Inspection-Type Emission Tests — In addition to the FTP testing, service-station, emission-control, inspection-type test data on hydrocarbon and carbon monoxide emissions were obtained on twenty-one cars. Additive concentrations were nominally 500 ppm and 1000 ppm. Data are tabulated in Appendix C and Table C-1. Duration of additive treatment varied from a flush through the fuel system by driving the car "around the block," to a more usual consumption of a full tank of treated fuel.

Table 5, summarizes the hydrocarbon emission results which show that the additive consistently reduced hydrocarbon emissions.

TABLE 5
EMISSION INSPECTION TEST SUMMARY

Concentration ppm	Number of Cars	HYDROCARBONS, % REDUCTION Minimum	Average	Maximum
500	16	10	62	100**
1000	5	2	70	100**

** 100% indicates additive reduced emissions below instrument detection limit.

1.6 L, 4-Cylinder Carburetted Engine — The emissions and fuel efficiency of the 1.6 L, 4-cylinder engine used in the ORI testing (Laboratory L-4) were also evaluated when the octane requirement was determined at 50 hour intervals. The data at equivalence ratios of 1.1, 1.0, 0.9 and 0.8 (13 to 18 A/F) with untreated and 424 ppm treated fuels are shown in Appendix D, Table D-1. Ignition timing was set at the minimum advance which gave best (highest) torque (MBT) at 40 Hz (2400 rpm) and 2.5 bar BMEP. Despite the fact that the engine was previously run-in for 20 hours over a range of speeds and loads, emissions and fuel efficiency evidenced an appreciable further break-in in the first 50 hours of the ORI test. Consequently, the Appendix Table D-1 and the following Table 6 summarize only the 50-200 hour steady state data.

TABLE 6
AVERAGE PERCENT DECREASE IN
FUEL CONSUMPTION AND EMISSIONS
424 ppm
1.6 L, 4-Cylinder Carburetted Engine
40 Hz, 2.5 Bar BMEP
MBT Timing, 50-200 Hour Average

Equivalence Ratio*	Fuel Consumption	HC	NOx	CO
1.1	0.3	-2.3**	15.9	-3.3
1.0	4.3	0.4	6.1	3.9
0.9	3.7	5.0	6.0	-3.3
0.8	1.2	-2.9	10.3	-1.5

* Equivalence ratio = $(A/F)_{stoich} / (A/F)$
** Negative decreases indicate increases

Table 6 shows that fuel consumption and NOx were both consistently reduced over the entire range of equivalence ratios. Hydrocarbon and carbon monoxide emissions both tend to be decreased near stoichiometric, but increased at the mixture extremes.

0.496 L Single-Cylinder Engine — Laboratory L-4 obtained additional emissions and fuel efficiency data in a 0.496 liter, single-cylinder engine, with a "bathtub" combustion chamber representative of many modern engine designs. The laboratory finds that the engine gives levels of performance representative of current gasoline engines. Data are given in Appendix D, Tables D-2 and D-3. Table 7 data cover a range of speeds and loads and treatment levels with MBT ignition-timing. Table 8 data are for five ignition settings with untreated fuel and fuel treated with 424 ppm. The 40 Hz and 2.5 bar BMEP condition for these tests was found to give the largest difference between treated and untreated fuel in spark advance for maximum torque.

TABLE 7
EFFECT OF OPERATING CONDITIONS ON PERCENT
DECREASE FROM UNTREATED FUEL
MBT Timing
0.496 L Single-Cylinder Engine
424 ppm, Stoichiometric A/F

Speed, Hz	BMEP, Bar	Fuel Consumption	HC	NOx	CO
40	2.5	-1.5	11.8	9.1	-1.7
40	5.5	0.1	2.0	-3.2	-0.1
20	5.5	0.4	1.9	5.6	-12.7
20	1.5	-0.3	7.9	-14.8	-0.5
15	0	-0.2	9.0	0.0	0.0

TABLE 8
TIMING EFFECT ON PERCENT DECREASE
IN FUEL CONSUMPTION AND EMISSIONS
0.496 L Single-Cylinder Engine
40 Hz, 2.5 bar BMEP
424 ppm, Stoichiometric A/F (14.5)

Timing, °BTDC	Fuel Consumption	HC	NOx	CO
25	2.4	4.7	7.0	3.0
30	1.6	14.0	5.1	13.2
35	-0.1	11.1	-0.3	-0.3
40	-1.3	6.0	-1.3	-26.7
45	-2.7	11.0	-8.8	-14.4

Table 7, with best torque ignition timing, indicates that 424 ppm treatment consistently decreases hydrocarbon emissions. Nitrogen oxide emissions may be either increased or decreased, depending on operating conditions. Carbon monoxide emissions are unaffected except at the high load of 5.5 bar at 20 Hz (1200 rpm). Data in the Appendix D, Table D-2 indicate that treatment with 848 ppm provides smaller and less consistent effects.

Increasing ignition advance is shown in Table 8 to have no systematic effect on percent decrease in hydrocarbon emissions. Fuel consumption, nitrogen oxide and carbon monoxide emissions increase when timing is advanced beyond the optimum for highest torque (about 35° BTDC for untreated fuel and 32° BTDC for treated fuel). Most engines have timing retarded from MBT to allow for manufacturing variations and to reduce exhaust emissions. With ignition retarded to 30° BTDC, Table 8 indicates that additive treatment would reduce fuel consumption by 1.6%, hydrocarbon emissions by 14%, NOx emissions by 5% and CO emissions by 13%.

FUEL ECONOMY — Significant improvements in fuel economy are realized with use of the additive in a variety of SI-engines with the engines tuned normally (i.e., not with gross variations in mixture ratio or spark-timing from manufacturer's recommendations). This is illustrated by the data shown in Figure 3. Tests are described in Appendix E, Table E-1.

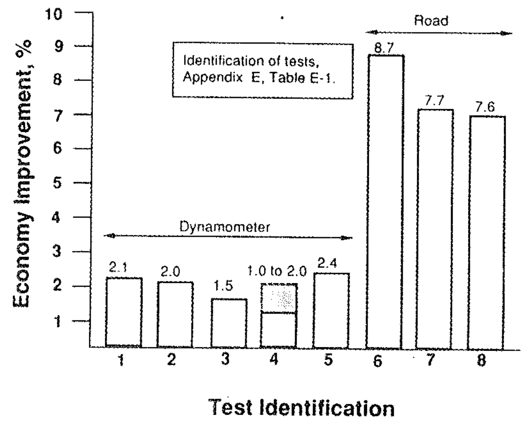
In Figure 3 the economy improvements for dynamometer evaluations 1 through 5 were obtained using engines which were relatively clean and/or had little accumulated mileage since manufacture or rebuilding. Conversely, the engines in 6, 7, and 8 were in over-the-road vehicles with considerable mileage. These would be expected to have deteriorated appreciably from a well-tuned state. The additive improved the fuel economy of the latter vehicles by significantly greater amounts than for the "nearly new" engines. Presumably, none of these engines had deteriorated sufficiently from normal mixture ratios or spark-timing to show the inconsistent effects illustrated in Table 5, 6, 7, and 8.

OCTANE NUMBER AND OCTANE RELATED ENGINE PERFORMANCE — The additive when incorporated in primary reference fuels and commercial gasoline has shown no significant effect on Research or Motor Octane Number, in limited testing by Laboratory L-2.

Laboratory L-4 measured octane number in the 0.496 L, single-cylinder engine used to obtain emissions and fuel economy data. Octane number at 1800 RPM and full-load was determined from the spark advance required to produce borderline knock. Additive concentrations of 424, 848 and 1700 ppm all produced borderline knock at 1 degree greater spark advance than for the untreated 91.5 RON gasoline. This corresponds to a 0.5 higher RON for the additive treated fuels.

Figure 3

Fuel Economy Improvement With the Additive, S.I. Engines



User reports suggest that in-service increases in effective octane number are greater than this slight increase.

VALVE SEAT RECESSION — Two exhaust valve seat recession tests were run by Laboratory L-4. The first was on a 1.2 L, European type, four cylinder, gasoline engine. The engine was run at wide-open throttle at a speed of 4500 rpm, for 55 hours. Every 5 hours the valve recession was measured. The cool-down time was kept constant to minimize temperature effects on these measurements.

Runs were made with untreated unleaded gasoline and with the gasoline trated with 848 and 424 ppm of the additive. The data are tabulated in Appendix Table F-1 and summarized in terms of average wear rates in Table 9. Untreated leaded gasoline data are also shown for comparison.

Data on the unleaded gasolines were analyzed by computation of the average recession rate for each valve for each five hour period. Paired untreated and treated recession rates for corresponding 5-hour time periods for each valve were examined statistically at both concentrations. Both the two-tailed binomial signs tests and the t-test indicate statistical significance at both concentrations ($p < 0.002$ and < 0.001, respectively at 424 ppm and $p < 0.008$ and < 0.01 at 848 ppm).

Table 9 averages indicate that additive treatment produces a 1.6 to 1.7-fold increase in average valve life and a 1.2-fold increase in worst valve life. It also indicates that leaded gasoline virtually eliminates wear.

TABLE 9
VALVE SEAT RECESSION RATES
1.2 L, 4-Cylinder

FUEL	NUMBER OF TESTS	AVERAGE VALVE µm/h	WORST VALVE µm/h
UNTREATED[1]	2	37.6	42.9
TREATED			
424 ppm(v)[1]	1	23.1	35.6
848 ppm(v)[2]	1	21.8	35.9
LEADED			
(150 mg/L)[1]	1	0.0	1.3

[1] 20-hr. test [2] 35-hr. test

An extensive series of valve recession tests, using unleaded gasoline, was also conducted by an engine manufacturer. These tests extended over a period of two years. The accumulated total running time on the engines reported here was 7108 hours, of which 4829 were run using the additive in the gasoline, and 2280 hours were run without.

The following engines were run both with and without the additive.

Engine Number	Configuration	Rated Power(kW)
1	4 cyl in-line	104
2	4 cyl in-line	142
3	V-8	194
4	V-8	205
5	V-6	153

All engines had induction-hardened valve seats.

The manufacturer used his standard durability test procedure, consisting of 55-minutes at full throttle and maximum load, followed by a 5-minutes idle period. The cycle was then repeated.

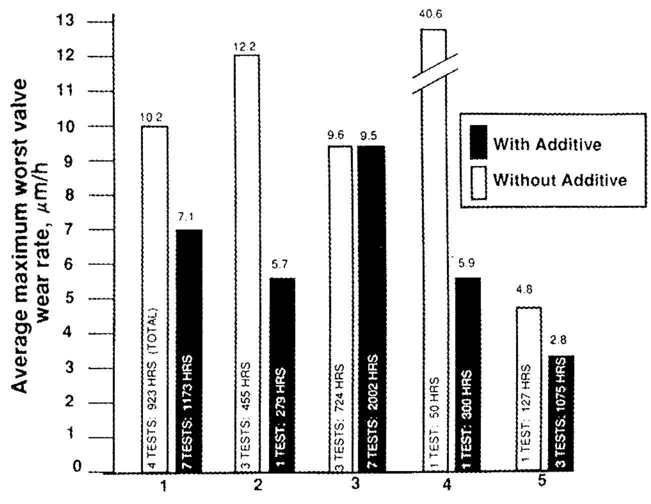
The tests were not formulated with paired tests of untreated and treated fuel or with frequent reference runs. Consequently, it is not possible to discount fluctuating variables of air/fuel ratio, fuel volatility, ambient test conditions, and the length of individual tests over the protracted period of testing. However, the data on 31 total tests in Appendix F, Table F-2 imply that the results were not influenced by such fluctuating variables. For comparative purposes, the manufacturer's raw data from the tests of different duration were analyzed by the authors and the author's conclusions were expressed as average wear rates over the test duration, even though it is known that rates vary with time during a test.

Nevertheless, the rather formidable collection of data, gathered over a prolonged period of time, through thousands of hours of testing, and with all of the variables present, does provide a consistent conclusion. The authors' conclusion from their analysis of the manufacturer's raw data is that valve seat wear rate reduction is significant when using the additive.

The data for each run are summarized in Appendix F, Table F-2 and average data for each engine model are in Table 10 and Figure 4. Data on any one engine model is too limited for statistical significance. However, combining the data from all five engines is adequate. The two-tailed t-test indicates that the mean recession rates are not the same with p ∨ 0.05 and p ∨ 0.01 for the worst valve and the average valve data, respectively. Thus, recession rates with treated fuel are significantly different from those with untreated fuel, provided that the usual assumptions for use of the t-test are satisfied.

Additional tests were run on six other engines using the additive. However, the engine manufacturer did not run comparative tests using untreated fuel. Therefore, although the data are available, they are not presented in this paper.

Figure 4
Four Cycle S.I. Engine
Valve Recession
Test Data



SUMMARY OF FLEET EXPERIENCES

Most of the foregoing text is based upon test results that characterize the behavior of the additive over short periods of time, under carefully controlled conditions.

The additive has also been evaluated for extended test periods, usually several years in duration, with a number of motor fleets. The nature of these data, although judged credible by the fleet manager, generally would not survive critical review and so are not tabulated in this paper. Highlights of these results from representative fleets, however, are included to demonstrate satisfactory field performance:

The types of fleets in which the additive was tested were 1) a large electric utility fleet of 654 vehicles, comprised of gasoline passenger cars and trucks, Diesel trucks, and miscellaneous machines; 2) a manufacturing plant fleet of approximately 1000 gasoline powered vehicles and 200 large Diesel trucks and construction vehicles; 3) a fleet of six police motorcycles; and 4), a utility which tested the additive in two aircraft-type, stationary gas

TABLE 10
AVERAGE VALVE SEAT RECESSION RATES
FOR EACH ENGINE MODEL
556 & 1000 ppm Treatment

Engine Number	Worst Valve, µm/h		Average Valve, µm/h		Total Test Hours	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
1	10.2	7.1	4.4	3.1	923	1173
2	12.2	5.7	6.9	4.8	455	279
3	9.6	9.5	3.7	4.1	724	2002
4	40.6	5.9	8.1	1.4	50	300
5	4.8	2.8	3.2	1.3	127	1075
Mean*	12.61	7.19	5.07	3.18		

* Mean calculated from average rate before rounding.

turbines. About five years of experience with the additive has been accumulated by the utility and plant fleets, and three years by the motorcycle fleet and gas turbines without observation of any adverse treatment effects.

The utility fleet reported that a troublesome valve burning problem had been eliminated by use of the additive, and that knocking and pinging problems also had been eliminated. They have treated in excess of 9,100 m^3 (2,400,000 gallons) of fuel with the additive.

Both fleets 1 and 2 noted improvements in fuel economy. Moreover, they together with fleet 3 were able to switch from 89 octane leaded gasoline to 87 octane unleaded without adverse effects.

A six-month comparative test was run with the motorcycle fleet. Three motorcycles used a base fuel; three used the same fuel but treated with the additive. Qualitative evaluations indicated both better throttle response and reductions in knock and pinging. The knock/pinging reduction is supported by Figure 5 which shows much smaller amounts of piston top deposits associated with use of the additive.

Lastly, in the gas turbine group 4, a 1% reduction in fuel consumption was noted.

ADDITIVE CONCENTRATION

At present, additive concentration has not been systematically investigated. However, consideration of the several concentrations tested for the various types of performance suggests an approximate optimum for gasoline to be in the vicinity of 500 ppm (i.e., between 300-700 ppm).

DISCUSSION

The additive performance suggests that it acts as a combustion modifier in engines. Further support for combustion modification is suggested by SI-engine work at Laboratory L-4. The single-cylinder 0.496 L engine and the 4-cylinder 1.6 L engine emission data were both obtained with ignition timing set to the minimum value giving the highest torque. Generally, the timing for the additive treated fuels was 1 to 3 or 4° BTDC less advanced than the untreated fuel (usually 1 to 2°). This is consistent with expectations if the additive treated fuels ignite and/or burn faster than untreated fuel.

More direct confirmation of combustion effects has been obtained by Laboratory L-4. Pressure signature data were obtained on the 0.496 L, single-cylinder SI-engine for which data are shown in Table 7 and on a 1.6 L IDI CI-engine. The pressure signature data were analyzed in terms of energy release. Results on the SI-engine show that the delay from ignition to 10% energy release and the time for 10% to 50% energy release are reduced, while peak pressure generally is not changed. Results in the IDI CI-engine similarly show that the ignition delay and the time to release 10-to-90% of the heat are both reduced. These SI- and CI-engine results will be detailed in a separate paper.

CONCLUSIONS

The results reported above show that the additive treats a broad spectrum of important gasoline related problems. The additive at 333-848 ppm:

1. Reduces the need for higher (R + M)/2 octane fuel by reducing octane requirement increase by about 70%.
2. Reduces exhaust hydrocarbon emissions by the order of 10% or more.
3. Reduces fuel consumption, by about 1.5% and often much more.
4. Reduces valve seat recession.

These additive effects appear to be the result of combustion modification.

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