

# **Effects of Oxygenates on Vehicle System Components**

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**TABLE OF CONTENTS**

	<b>Sections</b>	<b>Pages</b>
<b>I.</b>	<b>INTRODUCTION</b>	<b>1</b>
<b>II.</b>	<b>VEHICLES, FUEL INJECTORS, AND FUEL SYSTEMS</b>	<b>1</b>
<b>III.</b>	<b>PLASTICS, ELASTOMERS, AND METALS</b>	<b>4</b>
<b>IV.</b>	<b>FUEL TANKS</b>	<b>7</b>
<b>V.</b>	<b>CONCLUSION</b>	<b>9</b>
<b>VI.</b>	<b>REFERENCES</b>	<b>9</b>
<b>VII.</b>	<b>TABLES*</b>	<b>11</b>
<b>VIII.</b>	<b>FIGURES*</b>	<b>20</b>

*Effects of Oxygenates on Vehicle System Components*

\*NOTE: All tables and figures appear at the end of the report. All tables and figures 1-3 are from the California Environmental Protection Agency (CalEPA) "CaRFG: Performance and Compatibility Test Program." Figures 4-8 are from Kathios *et al.* "Permeation of Gasoline-Alcohol Fuel Blends Through High Density Polyethylene Fuel Tanks with Different Barrier Technologies."

## **I. INTRODUCTION**

Senate Bill 521 (Mountjoy) calls for an assessment of the impact of MTBE on vehicle parts and the efficient operation of vehicles. A cursory review of the available literature was undertaken to determine whether any detrimental effects on the vehicle system could be attributed to the introduction of MTBE into gasoline. To determine if MTBE was indeed the cause for some of vehicle system problems, industry and the federal government performed tests (CalEPA, 1996). Failure of the fuel system mainly occurs in the gaskets, rubber hoses, and parts in direct contact with fuel. Separating out the effects of the fuel additive from other factors affecting the fuel system is difficult. Other factors that should be considered are for example, the type and age of the vehicle, the materials used in the vehicles engine and exhaust systems, quality of gasoline used and even weather conditions.

## **II. VEHICLES, FUEL INJECTORS, AND EXHAUST SYSTEMS**

Some automobile owners have complained that their cars began to have problems when MTBE was put into use. To determine if the cause of the problems was indeed MTBE, tests were conducted using test and control fleets of cars (CalEPA, 1996). The Air Resources Board (ARB) study indicates that the vehicles used included all makes and models of passenger cars and trucks, ranging over the years from 1964 to 1995 with odometer readings as high as 230,000 miles. A brief summary of the information gained from these tests follows: 1) cars built during and after 1991 did not experience problems while those built prior to 1991 did; 2) cars built prior to and during 1986 and those vehicles that had accumulated mileage of 95,000 miles or greater were those that experienced the largest proportion of fuel system problems; 3) the age of the car and its maintenance history contributed to the failure of the fuel control systems. According to Kortum et al. (undated), "Fuel Economy and Engine Performance Issues", the use of the vehicle, weather and driving conditions, and improper maintenance contribute more to the performance problems than do oxygenated fuels. Many older cars have problems because they do not use a "closed loop" fuel system that monitors and adjusts the amount of fuel delivered to the engine to

## *Effects of Oxygenates on Vehicle System Components*

maintain the stoichiometric air-fuel ratio of 14.7 pounds of air to one pound of non-oxygenated gasoline.

Testing was also undertaken to determine the effect of MTBE on vehicle cold-starting behavior, fuel injectors, fuel systems, and exhaust systems. It was found that blending 15% MTBE in fuels provided easy cold and hot starting, sufficient freedom from vapor lock, and good all weather driveability. Tests performed using Sun Fuels with 15% MTBE demonstrated that it did not contribute to fuel injector plugging. From tests done by Volkswagen researchers using alcohol--gasoline blends, Decker and Haahtela concluded that the engines must be tailor-made to cold-start requirements (Automotive Engine, 69). Mixing compounds that contain oxygen with gasoline changes the volatility of the fuel which controls the starting capability and cold-engine driveability of the vehicle. The engines and fuels that are used must complement each other in order to get the best performance out of the vehicle.

Other factors can contribute to fuel injector problems. The driving pattern of the vehicle is an example. Deposit formation in the fuel injectors occurs during the hot soak period immediately after the engine shuts-off. Therefore, typical short, city-trip driving tends to increase port fuel injector deposit formation (Automotive Service Technical Manual, 1991). The higher temperatures also increase the deposits. The amount of deposits can also be affected by the rate of fuel weepage through an injector where fuel weepage is defined as the passage of fuel beyond the injector seat during the hot soak.

Sun Fuels performed a 50,000 mile vehicle emissions durability testing. The objective of this program was to see if fuels containing 15% MTBE would have deleterious effects on exhaust emissions over 50,000 miles of operation. The cars that were used for the program were those that represented the current technology used in cars. Overall, the tests showed that MTBE gave driveability, emissions and port fuel injector cleanliness performance better than the base gasoline.

### *Effects of Oxygenates on Vehicle System Components*

Sun Fuels also performed a test on evaporative losses in vehicle fuel line hoses and gasoline dispenser hoses. Results indicate that there were no significant differences in evaporative losses from hoses containing base fuel and those containing 15% MTBE. Dispenser hoses composed of Viton samples showed greater evaporative losses when tested using fuel containing either 50% aromatics or fuel containing 15% MTBE.

Industries such as Chevron ran on-road tests of their own in which employees volunteered their cars for the program. The incidents that occurred during the testing were not considered to be related to either the reformulated or conventional fuels (TABLE 1). The only possibility where fuel could have been the cause is in incidents involving the elastomers and seals. The average odometer readings for the test fleet's incidents were 105,000 miles, ranging from 24,000 miles and 202,000 miles. For the control fleet, the average odometer reading for incidents was 91,000 miles, ranging from 24,000 to 184,000 miles (Air Resources Board Test Program 2-8). The observed and normalized incident rates for both the control and test fleets were below that of the expected (TABLE 2). According to Chevron, none of the incidents that occurred were positively identified as being fuel-related. Possible reasons why these incidents occurred are because of the engine, fuel system, age of the vehicle, age of the parts in the vehicle, or maintenance of the vehicle. Vehicle age is a particularly important factor in governing the tendency to problems or failure.

Ford Motor Company ran lubricity tests to determine if CaRFG caused an increase in engine and component wear. The fuels were compared with the fuels used in the Auto/Oil Air quality Improvement Research Program. The results from the bench-top wear test indicate that higher contents of aromatics or oxygenates generally reduce the lubricity rating of fuel (Air Resources Board Test Program 2-17). These results do not indicate whether engines will be affected significantly in actual use, but an increased fuel wear rate is expected over the industry average fuel.

## *Effects of Oxygenates on Vehicle System Components*

Nissan Motor Company performed tests to compare how conventional gasoline and CaRFG fuels affected the formation of deposits in the intake valves and combustion chamber. The vehicle model used for testing the fuels (TABLE 4) was the Nissan Sentra 4-cylinder, spark ignition, internal combustion engine (TABLE 3) (Air Resources Board Test Program 2-35, 2-36). The results showed that the intake valve deposits were less while using the reformulated gasoline, the combustion chamber deposit formation with the reformulated fuel was the same with conventional gasoline, and there was no difference in deterioration of fuel system components between the reformulated and conventional gasoline (FIGURES 1, 2, & 3) (Air Resources Board Test Program 2-34, 2-35, & 2-36). Using reformulated fuels basically does not harm any of the intake or combustion components in a vehicle. The results are the same or better than the conventional fuel.

### **III. PLASTICS, ELASTOMERS, AND METALS**

Elastomers were tested by exposing them to MTBE over a period of time; the amount of swell was measured. Some elastomers are compatible with the use of MTBE. The elastomers that showed high compatibility are Kalrez 4019, Zalak 25OGP, and Zalak ZLX 93004 ("Fuel Reformulation" 44). These elastomers are also compatible with alcohols

Another factor that affects the swelling of an elastomer is the fuel's aromatic content. According to "Changes in Gasoline and the Automobile Service Technician", gasolines contain 25-40 percent aromatic compounds which have a "greater tendency to cause plastics and elastomers to soften, swell, crack and otherwise deteriorate" ("Changes in Gasoline and the Automotive Service Technician" 14). Newer vehicles are less likely to experience problems because the fuel systems have been upgraded to compensate for the use of high aromatic gasolines, ethers, and alcohols. Rubbers that have a high fluorine content provide the best resistance to MTBE.

Sun Fuels tested plastics and elastomeric parts in gasoline and gasoline containing 15% MTBE. It was found that there were not large differences in swell between the two materials except in

## *Effects of Oxygenates on Vehicle System Components*

Viton samples, which had a small level of swell of 7%. For some of the materials there was less swell with fuels using MTBE which indicates that it acted as a diluent. Many of the elastomeric hoses had slightly more volumetric swell with base fuels containing 50% aromatics and 15% MTBE.

EMCO Wheaton, Incorporated ran tests on four of their nozzles using winter and summer CaRFG test fuels and their own standard test fuel of 20% volume ethanol in premium grade. They evaluated the mechanical wear and deterioration caused by these fuels. The average volume % swell using the standard test fuel was greater than that of winter and summer CaRFG test fuels. The maximum allowable swell is 40% and allowable weight loss is 10% for the standard test fuel (Air Resources Board Test Program 2-14). The average weight loss was almost the same for each of the three fuels (TABLE 5). EMCO Wheaton claimed that the CaRFG fuels did not affect the performance of their equipment, nor did they deform the O-rings, seals, or diaphragms. The plastic and metal parts were also in good condition.

General Motors ran tests to measure the effects of CaRFG on unused fuel system elastomers and plastic materials. GM used two bench test procedures. In the first test, the fuel system plastics were "refluxed in the test fuel at the initial boiling point of the fuel" (Air Resources Board Test Program 2-20). The elastomers and the Saran/polyester fuel filter were reflux tested to 1000 hours and the foamed urethane and the Nitrophyl samples were reflux tested for 24 hours (Air Resources Board Test Program 2-20). In the second test, the samples were immersed in test fuel, in a sealed container called a Parr bomb. It was placed in an oven, and the test fuel and material were heated to 100 degrees Celsius. The results of the fuel system plastics (Table 6) show that the changes are not sufficient to affect their performance as carburetor materials. For the fuel system elastomers, changing to a lower aromatic fuel CaRFG-LA has not produced any major differences in property changes (Table 7, 8, 9, 10, I 1, and 12). In the reflux and Parr bomb tests, the results show little effect of the CaRFG blends on Viton A and epichlorohydrin samples, relative to RFA (Air Resources Board Test Program 2-28). The fluorosilicone samples showed large property changes in CaRFG blends relative to RFA during the first 500 hours of testing, but

## *Effects of Oxygenates on Vehicle System Components*

none to warrant concern. Nitrile elastomers had large property changes in both reflux and Parr bomb tests. The nitrile elastomers were used in older, carbureted fuel systems, but have been replaced by fluorocarbons or newer elastomers. This change is accounted for by the fact that CaRFG fuels are now being used, and nitrile does not seem to be compatible with them.

MTBE may affect the metal parts in a vehicle. The oxygen present in MTBE may cause oxidation. However, results have shown that there is no difference in corrosion performance of gasoline and gasoline containing 15% MTBE. Cast-iron and tin coated steel actually had a small weight gain with 15% MTBE blended fuels. The 10/20 steel samples showed a slight weight loss, but indicated no potential problems.

During the CaRFG Performance and Compatibility Test Program, the On-Road Data collected for the Driveability/Incident Logs showed that 2.9% of the test vehicles and 3.1% of the control vehicles may have had problems related to fuel (Air Resources Board Test Program 1-37). The percentage indicates that the deleterious effects of using reformulated gasoline is negligible since the same percentage was found using base fuels. Seeps were also found in 131 of the 829 test vehicles (Air Resources Board Test Program 1-38). Seeps are defined as a wet spot near a gasket, seal, or fitting which suggests that fuel may have seeped through that area. All the reported seeps found in the vehicles were "characterized" as normal to vehicle operations and should not affect the test results. The seeps were determined to be caused by a liquid other than gasoline such as coolants.

The incident rates for both test and control vehicles were also reported (TABLES 13 & 14). The incident rates were based for particular fleets upon odometer readings and model years of the vehicles. . For the observed values of the test and control fleets, the values were all less than the "expected" values. Problems occurred in the fuel pumps, carburetors, fuel lines, fuel injectors, and fuel tanks. Overall, the analysis indicated that differences in normalized rates (TABLE 15) should not be attributed to the differences in fuels used (Air Resources Board Test Program 1-55). Data collected from the on-road test program also indicated that the fuel system problems occurred in

vehicles where the mileage was more than 30,000 and 40,000 miles. Cars of older model years had higher rates of incidents. Cars that were models of 1991 or older were not observed to have problems. Cars that were made pre-1981 had incident rates lower than those of 1981 and 1984 models. The Performance and Compatibility Test Program indicates that there are two reasons why this has occurred. One reason is that the sample sizes were small and the other reason is that many of the pre-1981 vehicles had their fuel system components replaced with new ones (Air Resources Board Test Program 1-57).

#### **IV. FUEL TANKS**

At present, the automobile industry uses high-density polyethylene (HDPE) to fabricate fuel tanks (Kathios 1). Untreated HDPE is permeable to the constituents of gasoline, which is the reason why fuel tanks are being produced with various barrier technologies to reduce the permeation rate of fuels. HDPE fuel tanks are preferred over the conventional steel tanks because they do not corrode, they are lighter than steel, and there are "less packaging restrictions involved in their fabrication" which allows designers to take advantage of the space under the vehicle (Kathios 1).

There are four types of barrier technologies that are currently available. They are fluorination, sulfonation, coextrusion, and the laminar barrier technology. The fluorination process is "integrated directly into the blow molding process - the process by which the fuel tanks are industrially fabricated" (Kathios 1). In this process, a compressed gas of fluorine and nitrogen is injected into polyethylene to create a mold. The fluorine then replaces the exposed hydrogen atoms on the surface of the polyethylene surface (Figure 4). The fluorination process creates a barrier on the inner surface of the fuel tank. In the sulfonation process, sulfur trioxide is introduced to the inside of an untreated HDPE fuel tank after the blow molding process has already taken place" (Kathios 1). A reaction occurs between the exposed sulfur trioxide and the exposed polyethylene causing sulfonic groups to form in the inner surface of the tank (Figure 5). Ammonium hydroxide is introduced into the tank to neutralize acidic by-products formed during

the reaction (Kathios 2). The tank is then rinsed with water to remove any excess ammonium hydroxide solution and neutralized by-products. The sulfonation process creates a barrier on the inner surface of the fuel tank. Both the fluorination and sulfonation processes decrease the permeation rate by reducing the solubility of gasoline in the inner surface of the fuel tank (Kathios 2). These technologies may also change the molecular structure of the inner surface of the tanks, thus causing it to be more tightly packed than untreated HDPE. This results in less surface solubility.

According to Kathios, "the coextrusion barrier technology involves the fabrication of a multilayer HDPE fuel tank with a thin, continuous nylon layer present within the wall of the tank" (Kathios 2). The nylon layer is impermeable to the constituents of gasoline, thus reducing the permeation rate (Figure 6). The laminar barrier technology uses a polar polymer that is mixed with "virgin HDPE prior to the blow mold process" (Kathios 2). The resulting wall of a series of polar polymer baffler platelets in the fuel tank creates a longer and harder path for the fuel to permeate through. The increased path thus results in overall decrease in the permeation rate (Figure 7).

These four barrier technologies were successful when used with pure gasoline, but their effectiveness diminished when alcohols were introduced into the gasoline. Despite this setback, the fluorination process seemed to be the best solution to reducing permeation with alcohol blends. Improvements had to be made to the fluorination process to compensate for the alcohol blends. More of the oxygen groups had to be removed during the blow mold process resulting in "optimized" or "super" fluorination. The permeation rate with the standard fluorination barrier treatment decreased to less than 0.8 grams per day with pure gasoline, but with the alcohol blends, the permeation rate was reduced to less than 0.25 grams per day with the optimized fluorinated tanks, and to less than 0.07 grams per day with the super fluorinated tanks (Figure 8) (Kathios 9). The sulfonation process is also an excellent barrier against permeation, but it is inconsistent from fuel tank to fuel tank (Kathios 9). Since HDPE is preferred over steel fuel tanks, it is important to improve the processes that reduce the permeation rates of the fuels to compensate for the fact that alcohols and oxygenates are now mixed with gasoline.

## **V. CONCLUSIONS**

Drawing from a number of articles that reported on studies done on reformulated fuels, it can be concluded that MTBE does not affect the performance or longevity of the vehicle. The problems that occur within the vehicles themselves are primarily attributable to the condition of the car and its maintenance history. The effects of MTBE on a number of vehicle components are also seen when using a base fuel. Older vehicles fail because they are not compatible with MTBE. Hence, the parts within the vehicle are replaced with more up-to-date components when a car is brought in for maintenance. When MTBE is used, certain toxic emissions such as benzene are reduced while others like formaldehyde increase. It is a small trade off, which could be reduced by using a three-way catalyst. Though it is helpful in reducing toxic emissions, some MTBE is released unburned into the atmosphere, especially during engine cold starts and refueling operations. When using MTBE, the rubber hoses are the main parts that need to be replaced with more compatible, elastomeric parts which are also less expensive. The barrier technologies used in the fuel tanks should also be improved to compensate for the use of alcohol and oxygenated fuels.

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*Effects of Oxygenates on Vehicle System Components*

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VII. TABLES

**Table 1**  
**Chevron Test Fuel Parameters**

Fuel Parameter	On-Road Test Fuel (Summer) <sup>1</sup>	Chevron Test Fuel <sup>2</sup>	Conventional/Control Fuel <sup>2</sup>
Aromatics, vol%	18.4	13.7	25.1
Benzene, vol%	0.89	0.24	2.2
RVP, psi	6.6	8.3	13.0
T50, °F	190	183	182
T90, °F	298	288	306
Sulfur, ppmw	52	15.5	107
Oxygen, wt%	2.09	2.1	1.9
Olefins, vol%	5.7	5.0	14

Source:

1. Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.
2. Chevron Corporation. July 18, 1995. "Presentation to Performance Subcommittee." Sacramento, California.

**Table 2**  
**Observed, Expected and Normalized Incident Rates**  
**On-Road and Chevron Fleets Combined**

Component Type	Test Fleet				Control Fleet			
	Vehicles	Observed	Expected	Normalized	Vehicles	Observed	Expected	Normalized
Fuel Pumps	947	1.6%	2.0%	1.6%	754	0.9%	1.6%	1.3%
Fuel Lines	947	0.5%	1.8%	0.5%	754	0.0%	1.5%	0.3%
Carburetors	947	1.0%	2.1%	1.0%	252	1.2%	1.5%	1.8%
Fuel Injectors	947	0.0%	0.7%	0.1%	754	0.0%	0.8%	0%
Fuel Tanks	947	0.0%	1.3%	0%	754	0.7%	1.1%	0.9%
<b>Total</b>	<b>947</b>	<b>3.2%</b>	<b>7.9%</b>	<b>3.2%</b>	<b>754</b>	<b>2.8%</b>	<b>6.5%</b>	<b>4.2%</b>

Source: Chevron Corporation. July 18 1995. "Presentation to Performance Subcommittee." Sacramento, California.

Air Resources Board. 1995. *Baseline Data: California Reformulated Gasoline Project*. Sacramento, California.

**Table 3**  
**Vehicle Engine Specifications**

Base Model	MY1993 Sentra (B13) California
Engine	GA16 - L4 1.6L 4CYL DOHC Fuel System: Multi-point EFI with EGR
Catalyst	Close-coupled catalyst, underfloor catalyst
O2 Sensor	ZrO2

Source: Nissan Motor Company, September 19, 1995. Status report presented to the Performance Subcommittee, Sacramento, California.

**Table 4**  
**Nissan Test Fuels**

Fuel Parameter	RFG	Conventional
RVP (at 100 °F), psi	6.43	9.85
Sulfur, ppmw	37	232
Benzene, vol%	0.9	1.8
Aromatics, vol%	22.0	31.1
Olefins, vol%	4.3	7.2
MTBE, vol%	12.8	0.0
Gum Content, mg/100ml - Unwashed	2.4	2.0
Gum Content, mg/100ml - Washed	0.4	1.4
T50, F	200	190
T90, F	301	292

Source: Nissan Motor Company, September 19, 1995. Status report presented to the Performance Subcommittee, Sacramento, California.

**Table 5**  
**Results of EMCO Wheaton Immersion Testing**  
**(Standard Test Fuel<sup>1</sup> Versus CaRFG)**

Component	Standard Test Fuel		Winter CaRFG Test Fuel		Summer CaRFG Test Fuel	
	Volume Swell (%)	Weight Loss (%)	Volume Swell (%)	Weight Loss (%)	Volume Swell (%)	Weight Loss (%)
Diaphragm	--	--	34	0	26	2
O-ring (press. cap)	23	7	8	6	9	7
O-ring (spout)	28	8	8	6	4	10
O-ring (dia-cap)	26	7	6	7	4	10
O-ring (vapor guide)	7	0	4	0	3	1
O-ring (fuel inlet)	23	10	9	4	7	9
Disc Seal	5	0	3	0	2	0
O-ring (main cage)	24	7	16	0	8	5
Vapor Seal	32	5	13	3	12	4
Boot Face	37	0	4	0	4	0
Vapor Bellows	25	0	7	0	14	0
P/D Assembly	28	9	8	8	7	8
Average	24	5	10	3	8	5

Source: EMCO Wheaton. 8/23/95. "Inter-Office Correspondence Regarding CARB Fuel Testing." Wilson, North Carolina.

1. 80% premium and 20% ethanol. Maximum allowable swell is 40%; maximum allowable weight loss is 10%.

**Table 6**  
**Summary of Weight Percent Change of Reflux Tests**  
**Fuel System Plastic Materials**

Material	CaRFG-T	CaRFG-E	CaRFG-LA	RFA	ASTM-C
Saran/Polyester Fuel Filter (1000 hours reflux) <sup>1</sup>	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%
Foamed Urethane Floats (24 hours reflux)	-1.0%	-0.3%	-1.6%	-1.8%	-1.7%
Nitrophenyl Floats (Foamed Nitrile) (24 hours reflux)	-0.28%	-0.03%	-0.28%	-0.24%	-0.05%

Source: General Motors Corporation, February 1996, *Bench Test for the Performance Subcommittee*, Detroit, Michigan.

1. At 500 hours test time, CaRFG and RFA samples switched to CaRFG-LA.

**Table 7**  
**Summary of Parr Bomb Tests**  
**Fuel System Plastic Materials**  
**500 Hour Results**

Percent Change in Material Property	CaRFG-T	CaRFG-E	CaRFG-LA	RFA	ASTM-C
<b>Polybutylene Terephthalate (PBT)</b>					
Tensile Strength	-21%	-76%	-17%	-25%	-33%
Ultimate Elongation	2%	-77%	12%	9%	8%
Tensile Modulus	-17%	-24%	-18%	-22%	-34%
Izod Impact Strength <sup>1</sup>	---	---	---	---	---
Volume	2.5%	4.3%	2.3%	3.7%	5.0%
Weight	1.7%	2.6%	1.4%	2.2%	3.0%
<b>Polyphenylene Sulfide (PPS)</b>					
Tensile Strength	6%	2%	3%	9%	16%
Ultimate Elongation	-9%	12%	9%	16%	17%
Tensile Modulus	-5%	-6%	-2%	-2%	-4%
Izod Impact Strength <sup>1</sup>	---	---	---	---	---
Volume	0.4%	1.4%	0.3%	1.6%	3.2%
Weight	0.4%	1.1%	0.2%	0.8%	2.1%

Source: General Motors Corporation, February 1996. *Bench Test for the Performance Subcommittee*, Detroit, Michigan.

1. Not Tested by General Motors Corporation.

**Table 8**  
**Summary of Parr Bomb Tests**  
**Fuel System Plastic Materials**  
**1000 Hour Results**

Percent Change in Material Property	CaRFG-T <sup>1</sup>	CaRFG-E <sup>1</sup>	CaRFG-LA	RFA <sup>1</sup>	ASTM-C
<b>Polybutylene Terephthalate (PBT)</b>					
Tensile Strength	-31%	-76%	-22%	-26%	-37%
Ultimate Elongation	-26%	-73%	-1%	-10%	-11%
Tensile Modulus	-14%	-9%	-15%	-19%	-26%
Izod Impact Strength <sup>1</sup>	-30%	-36%	-17%	-20%	-11%
Volume	2.8%	3.8%	2.6%	3.0%	4.8%
Weight	1.6%	2.0%	1.4%	1.7%	2.8%
<b>Polyphenylene Sulfide (PPS)</b>					
Tensile Strength	-11%	-2%	-11%	-8%	-6%
Ultimate Elongation	-8%	4%	-26%	-4%	11%
Tensile Modulus	-3%	-4%	-3%	-3%	-8%
Izod Impact Strength <sup>1</sup>	-9%	-5%	9%	-9%	9%
Volume	0.8%	1.2%	0.4%	1.0%	3.6%
Weight	0.5%	0.8%	0.2%	0.6%	2.2%

Source: General Motors Corporation, February 1996. *Bench Test for the Performance Subcommittee*, Detroit, Michigan.

1. At 500 hours test time, CaRFG and RFA test fuels switched to CaRFG-LA for balance of test.

Effects of Oxygenates on Vehicle System Components

**Table 4**  
**Summary of Reflux Tests**  
**Fuel System Elastomers**  
**500 Hour Results**

Percent Change in Material Property	CoRFG-T	CoRFG-E	CoRFG-LA	RFA	ASTM-C
<b>Fluorocarbon-VITON A</b>					
Hardness	-12.1%	-17.3%	-13.8%	-10.3%	-14.4%
Ultimate Elongation	-13.6%	-7.1%	-13.8%	-20.8%	-29.6%
Tensile Strength	-30.2%	-35.1%	-28.6%	-25.1%	-37.7%
Volume	13.1%	14.3%	12.5%	11.5%	18.6%
<b>Epichlorohydrin</b>					
Hardness	-17.1%	-23.7%	-11.0%	-24.2%	-50.8%
Ultimate Elongation	-26.1%	-37.4%	-41.8%	-36.1%	-57.0%
Tensile Strength	-4.1%	-13.5%	-5.2%	-11.5%	-39.9%
Volume	12.3%	14.8%	7.5%	15.4%	28.1%
<b>Fluorosilicone</b>					
Hardness	-23%	-28.6%	-23.0%	-9.0%	-19.8%
Ultimate Elongation	-35.4%	-24.0%	-30.4%	-31.4%	-31.6%
Tensile Strength	-32.9%	-40.8%	-28.6%	-17.0%	-27.7%
Volume	20.6%	16.5%	17.2%	14.7%	19.2%
<b>Nitrile</b>					
Hardness	-9.7%	0.4%	7.4%	-25.7%	-13.4%
Ultimate Elongation	-30.0%	-27.1%	-17.0%	-59.4%	-42.4%
Tensile Strength	-12.6%	-12.1%	-2.0%	-59.3%	-17.2%
Volume	15.1%	7.5%	0.9%	21.2%	14.7%

Source: General Motors Corporation, February 1996. *Batch Test for the Performance Subcommittee*, Detroit, Michigan.

**Table 4a**  
**Summary of Reflux Tests**  
**Fuel System Elastomers**  
**1000 Hour Results**

Percent Change in Material Property	CoRFG-T <sup>1</sup>	CoRFG-E <sup>1</sup>	CoRFG-LA	RFA <sup>1</sup>	ASTM-C
<b>Fluorocarbon-VITON A</b>					
Hardness	-12.5%	-12.3%	-10.8%	-12.3%	-8.8%
Ultimate Elongation	-14.2%	-9.5%	-21.8%	-9.5%	-31.8%
Tensile Strength	-26.4%	-29.5%	-34.3%	-29.5%	-32.4%
Volume	12.8%	13.5%	12.1%	13.3%	10.4%
<b>Epichlorohydrin</b>					
Hardness	-11.0%	-2.2%	-5.9%	-8.7%	-6.4%
Ultimate Elongation	-41.4%	-41.0%	-45.1%	-38.3%	-41.0%
Tensile Strength	-10.9%	-10.3%	-13.9%	-14.2%	-9.1%
Volume	8.2%	2.4%	5.3%	5.8%	2.6%
<b>Fluorosilicone</b>					
Hardness	-0.206	-17.6%	-19.0%	-16.2%	-16.6%
Ultimate Elongation	-0.328	-37.3%	-28.8%	-38.2%	-27.3%
Tensile Strength	-0.176	-30.7%	-27.7%	-30.5%	-28.1%
Volume	0.178	17.9%	18.1%	20.5%	14.1%
<b>Nitrile</b>					
Hardness	10.6%	5.8%	7.3%	1.6%	6.5%
Ultimate Elongation	-29.6%	-23.9%	-21.1%	-58.0%	-33.8%
Tensile Strength	-9.1%	-8.0%	-3.3%	-54.4%	-5.3%
Volume	0.2%	-1.7%	-0.0%	-0.5%	-0.6%

Source: General Motors Corporation, February 1996. *Batch Test for the Performance Subcommittee*, Detroit, Michigan.

1. At 500 hours test time, CoRFG and RFA test fuels switched to CoRFG-LA for balance of test.

Effects of Oxygenates on Vehicle System Components

Table 11  
Summary of Parr Bomb Tests  
Fuel System Elastomers  
500 Hour Results

Percent Change in Material Property	CaRFG-T	CaRFG-E	CaRFG-LA	RFA	ASTM-C
<b>Fluorocarbon-VITON A</b>					
Hardness	-13.7%	-18.8%	-12.9%	-13.3%	-18.0%
Ultimate Elongation	-4.7%	-13.1%	-14.3%	-13.6%	-17.2%
Tensile Strength	-32.0%	-44.8%	-34.6%	-29.4%	-38.7%
Volume	16.1%	20.0%	15.2%	15.1%	23.3%
<b>Epichlorohydrin</b>					
Hardness	-11.5%	-26.7%	-11.9%	-21.5%	-41.8%
Ultimate Elongation	-49.6%	-41.8%	-42.9%	-51.7%	-42.7%
Tensile Strength	-17.8%	-19.6%	-16.0%	-24.4%	-35.0%
Volume	8.1%	16.8%	8.0%	15.7%	32.0%
<b>Fluorosilicone</b>					
Hardness	-27.6%	-38.0%	-24.6%	-21.2%	-59.4%
Ultimate Elongation	-34.8%	-23.8%	-25.9%	-38.1%	-23.3%
Tensile Strength	-44.5%	-48.8%	-34.1%	-39.3%	-16.3%
Volume	24.8%	18.4%	18.4%	17.4%	23.6%
<b>Nitrile</b>					
Hardness	16.7%	-3.6%	16.4%	5.7%	-3.3%
Ultimate Elongation	-51.3%	-50.7%	-54.2%	-43.5%	-43.7%
Tensile Strength	-23.9%	-31.2%	-20.9%	-20.5%	-14.0%
Volume	0.4%	6.2%	-0.3%	4.5%	13.0%

Source: General Motors Corporation, February 1996. Bench Test for the Performance Subcommunes, Detroit, Michigan.

Table 11  
Summary of Parr Bomb Tests  
Fuel System Elastomers  
1000 Hour Results

Percent Change in Material Property	CaRFG-T <sup>1</sup>	CaRFG-E <sup>1</sup>	CaRFG-LA	RFA <sup>1</sup>	ASTM-C
<b>Fluorocarbon-VITON A</b>					
Hardness	-12.9%	-14.9%	-11.2%	-10.8%	-12.5%
Ultimate Elongation	-21.5%	-19.0%	-21.0%	-21.2%	-15.0%
Tensile Strength	-37.8%	-40.7%	-34.6%	-36.2%	-34.2%
Volume	16.0%	16.4%	16.1%	16.8%	16.3%
<b>Epichlorohydrin</b>					
Hardness	-6.4%	-14.0%	-11.8%	-8.2%	-7.5%
Ultimate Elongation	-51.7%	-36.7%	-40.3%	-48.5%	-41.8%
Tensile Strength	-24.0%	-41.4%	-41.2%	-28.8%	-33.1%
Volume	7.2%	6.9%	8.6%	8.2%	6.3%
<b>Fluorosilicone</b>					
Hardness	-0.236	-24.8%	-22.2%	-22.8%	-55.8%
Ultimate Elongation	-0.292	-32.2%	-39.4%	-40.5%	-40.8%
Tensile Strength	-0.394	-40.1%	-43.8%	-43.6%	-58.1%
Volume	0.195	15.7%	19.3%	24.7%	27.7%
<b>Nitrile</b>					
Hardness	23.5%	22.8%	14.1%	25.1%	19.7%
Ultimate Elongation	-91.7%	-90.8%	-89.9%	-90.3%	-87.7%
Tensile Strength	-64.9%	-64.1%	-58.5%	-54.8%	-55.5%
Volume	-1.5%	-1.8%	-1.9%	-2.2%	-2.1%

Source: General Motors Corporation, February 1996. Bench Test for the Performance Subcommunes, Detroit, Michigan.

1. At 500 hours test time, CaRFG and RFA test fuels switched to CaRFG-LA for balance of test.

Effects of Oxygenates on Vehicle System Components

**Observed Incidents and Incident Rates<sup>1</sup>  
in the On-Road Test Program**

Incident Type	Test Fleet (329 vehicles)		Control Fleet (637 vehicles)	
	# Observed	Rate	# Observed	Rate
<b>Light-Duty</b>				
Fuel Pumps	4	1.0%	0	0.0%
Carburetors	1	0.5%	2	0.6%
Fuel Lines	0	0.0%	0	0.0%
Fuel Injectors	0	0.0%	0	0.0%
Fuel Tanks	0	0.0%	0	0.0%
<b>Subtotal</b>	<b>5</b>	<b>1.3%</b>	<b>2</b>	<b>0.6%</b>
<b>Medium- &amp; Heavy-Duty</b>				
Fuel Pumps	8	1.8%	6	1.9%
Carburetors	7	1.6%	7	2.3%
Fuel Lines	3	0.7%	0	0.0%
Fuel Injectors	0	0.0%	0	0.0%
Fuel Tanks	0	0.0%	5	1.6%
Other	1	0.2%	0	0.0%
<b>Subtotal</b>	<b>19</b>	<b>4.4%</b>	<b>18</b>	<b>5.8%</b>
<b>Total</b>				
Fuel Pumps	12	1.4%	6	0.9%
Carburetors	8	1.0%	9	1.4%
Fuel Lines	3	0.4%	0	0.0%
Fuel Injectors	0	0.0%	0	0.0%
Fuel Tanks	0	0.0%	5	0.8%
Other	1	0.1%	0	0.0%
<b>Total</b>	<b>24</b>	<b>2.9%</b>	<b>20</b>	<b>3.1%</b>

Source: Air Resources Board, 1995. *Air Resources Board Oracle Database System/Reformulated Gasoline Project*, Sacramento, California.

1. The totals may not match perfectly because values are rounded to the nearest decimal.

**Table K  
Observed and Expected Incident Rates<sup>1</sup>  
for On-Road Test and Control Fleets**

	Test Fleet		Control Fleet	
	Observed	"Expected"	Observed	"Expected"
<b>Light-Duty</b>				
Fuel Pumps	1.0%	1.0%	0.0%	0.8%
Carburetors	0.3%	0.8%	0.6%	0.5%
Fuel Lines	0.0%	0.8%	0.0%	0.7%
Fuel Injectors	0.0%	0.7%	0.0%	0.8%
Fuel Tanks	0.0%	0.5%	0.0%	0.5%
<b>Overall</b>	<b>1.3%</b>	<b>3.8%</b>	<b>0.6%</b>	<b>3.3%</b>
<b>Medium- &amp; Heavy-Duty</b>				
Fuel Pumps	1.8%	3.1%	1.9%	2.6%
Carburetors	1.6%	3.5%	2.3%	2.6%
Fuel Lines	0.7%	2.9%	0.0%	2.5%
Fuel Injectors	0.0%	0.7%	0.0%	0.9%
Fuel Tanks	0.0%	2.3%	1.6%	1.9%
<b>Overall</b>	<b>4.4%</b>	<b>12.4%</b>	<b>5.8%</b>	<b>10.5%</b>
<b>Total</b>				
Fuel Pumps	1.4%	2.1%	0.9%	1.7%
Carburetors	1.0%	2.2%	1.4%	1.5%
Fuel Lines	0.4%	1.9%	0.0%	1.6%
Fuel Injectors	0.0%	0.7%	0.0%	0.8%
Fuel Tanks	0.0%	1.4%	0.8%	1.2%
<b>Overall</b>	<b>2.9%</b>	<b>8.3%</b>	<b>3.1%</b>	<b>6.8%</b>

Source: Air Resources Board, 1995. *Reformulated Gasoline Project*, Sacramento, California.

1. Incidents of the "other" category were not included in the direct comparison.

**Table 15**  
**Comparison of Normalized<sup>1</sup> Incident Rates**  
**For Test and Control Fleets in the On-Road Test Program**

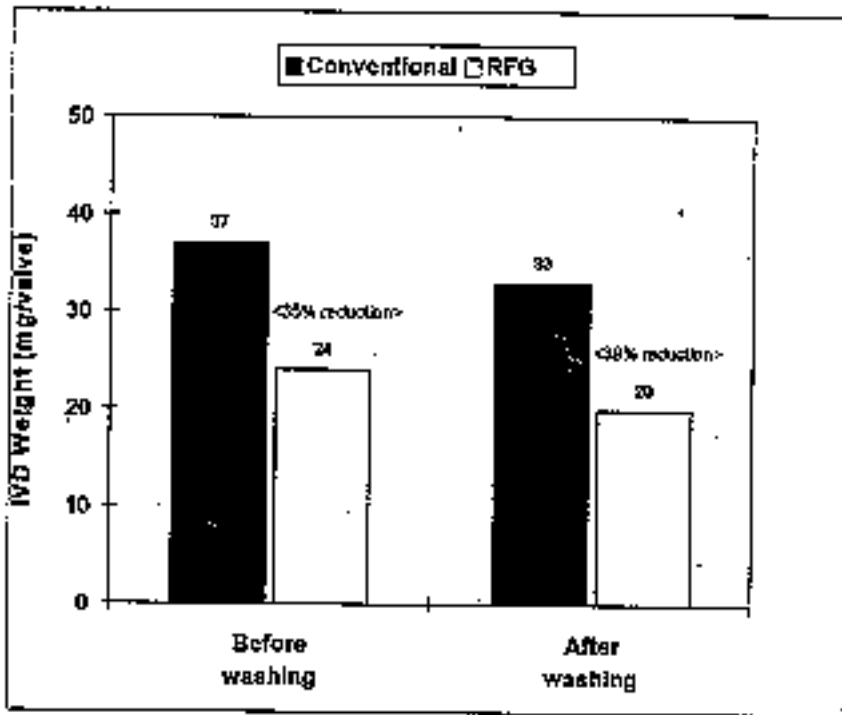
Incident Type	Test Fleet	Control Fleet
<b>Light-Duty</b>		
Fuel Pumps	1.0%	0.1%
Carburetors	0.3%	0.9%
Fuel Lines	0.0%	0.1%
Fuel Injectors	0.1%	0.0%
Fuel Tanks	0.0%	0.1%
Subtotal	1.3%	1.1%
<b>Medium- &amp; Heavy-Duty</b>		
Fuel Pumps	1.8%	2.5%
Carburetors	1.6%	3.1%
Fuel Lines	0.7%	0.4%
Fuel Injectors	0.2%	0.0%
Fuel Tanks	0.0%	1.9%
Subtotal	4.4%	7.8%
<b>Total</b>		
Fuel Pumps	1.4%	1.4%
Carburetors	1.0%	2.1%
Fuel Lines	0.4%	0.3%
Fuel Injectors	0.1%	0.0%
Fuel Tanks	0.0%	1.0%
Total	2.9%	4.7%

Source: Air Resources Board, 1995. *Baseline Data: Reformulated Gasoline Project*  
 Sacramento, California.

1. Incidents of the "other" category were not included in the direct comparison.

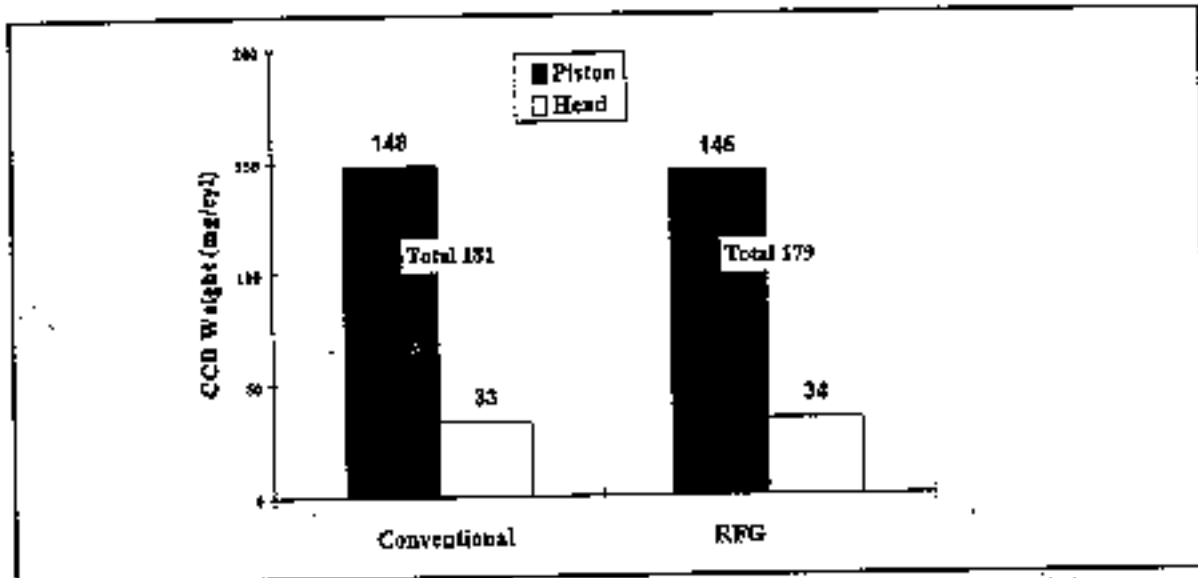
VIII. FIGURES

**Figure 4**  
**Intake Valve Deposits Determined from In-Use Testing**



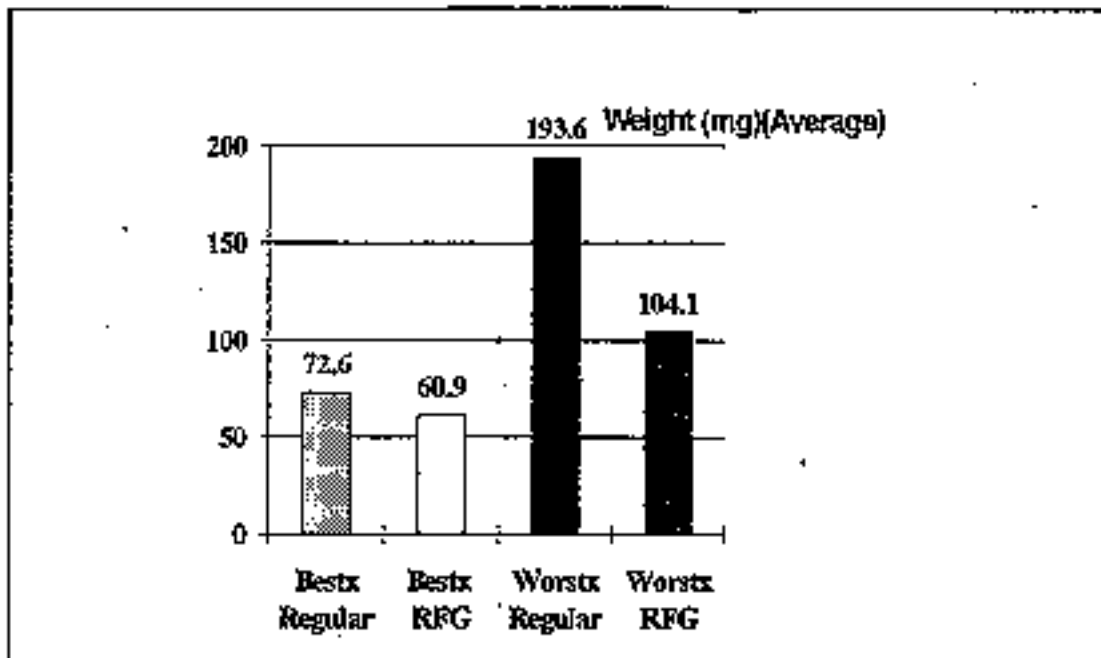
Source: Nissan Motor Company. September 19, 1995. Status report presented to the Performance Subcommittee. Sacramento, California.

**Figure 1**  
**Combustion Chamber Deposits Determined from In-use Testing**



Source: Nissan Motor Company. September 19, 1995. Status report presented to the Performance Subcommittee. Sacramento, California.

**Figure 2**  
**Average Intake Valve Deposits Determined from Bench Testing**



Source: Nissan Motor Company. September 19, 1995. Status report presented to the Performance Subcommittee. Sacramento, California.

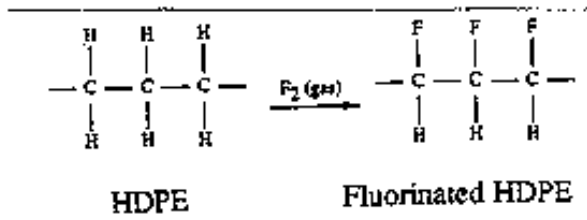


Figure 4: The fluorination process.

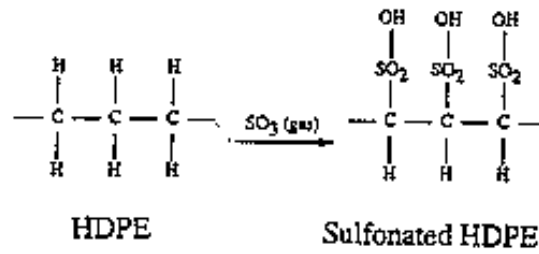


Figure 5: The sulfonation process.

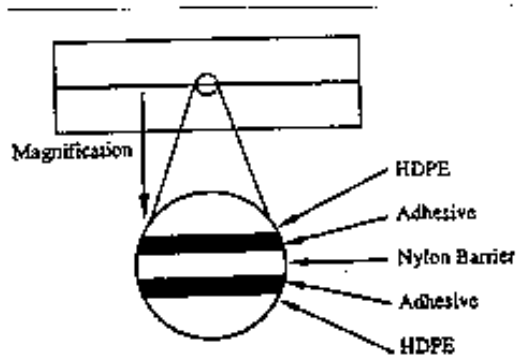


Figure 6: Cross-sectional view of the wall of a coextruded multilayer HDPE fuel tank.

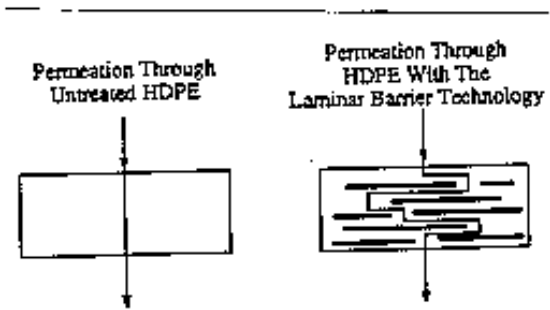


Figure 7: Diagram of the wall of a fuel tank with the laminar barrier technology. Diagram shows how the presence of the barrier platelets decreases the overall permeation rate by increasing the overall path length required by the solvent to pass through the plastic medium.

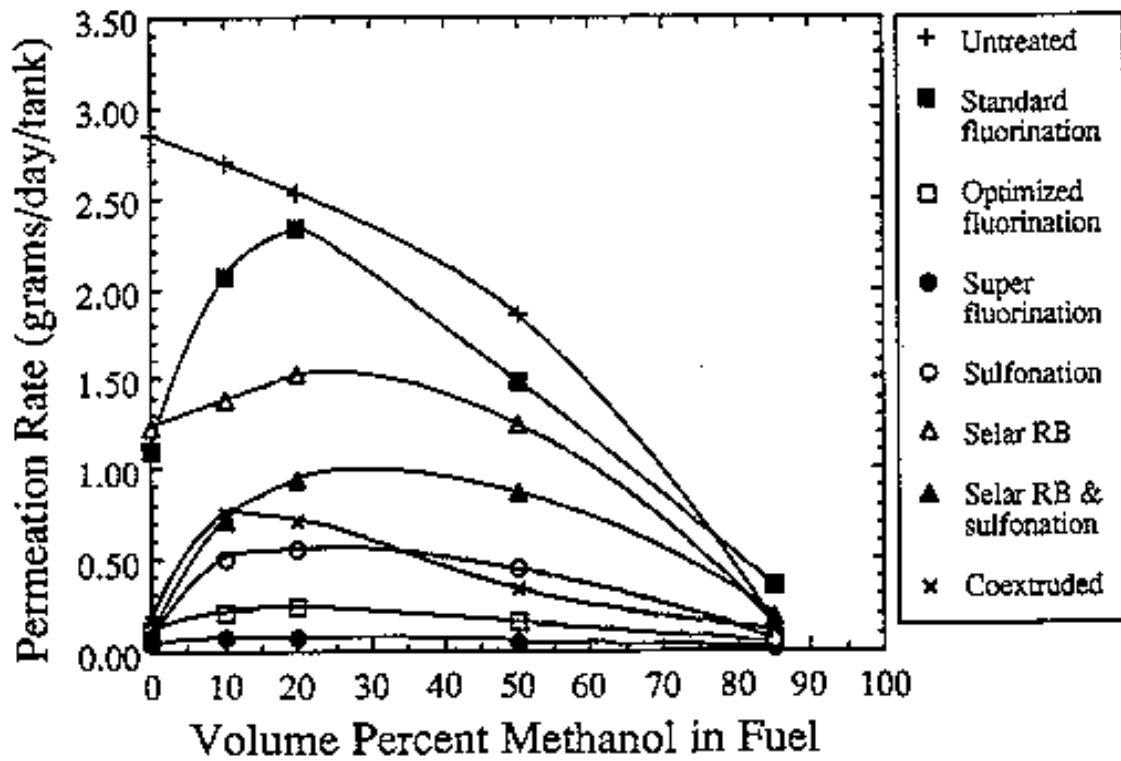


Figure 8: Permeation rates of gasoline-methanol fuel blends through 22-gallon HDPE fuel tanks with and without different barrier technologies. Tanks are 20% full and at room temperature.