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Technical Report

Vehicle Driveability with Gasoline/Alcohol Blends

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VEHICLE DRIVEABILITY WITH GASOLINE/ALCOHOL BLENDS

1.0 INTRODUCTION

Gasoline/alcohol blends such as gasohol (90% unleaded gasoline/10% ethanol) and ARCO's Oxinol blend (unleaded gasoline with a maximum of 4.75% methanol and 4.75% tertiary butyl alcohol [TBA]) have been successfully marketed for a number of years now. Also, EPA has approved a waiver from the requirements in section 211 of the Clean Air Act for a blend prepared by DuPont. This blend includes 5% methanol with 2.5% cosolvent alcohols such as ethyl, propyl, or butyl alcohols. It has not been commercially marketed yet because of industry's apparent concern about the feasibility of economically meeting the volatility restrictions associated with the waiver approval. These volatility restrictions are designed to help assure that the evaporative emissions of vehicles using the blend do not increase compared to those of the same vehicles using the gasoline it would displace.

Many oxygenated blends have been evaluated in a variety of test programs conducted by oil companies, other fuel developers, vehicle manufacturers, EPA, DOE, and other interested parties. While there are many issues involved in the decisions about the desirability of such fuels (economics, alcohol supply, octane enhancement, vehicle driveability, emissions, fuel volatility levels, etc.), this paper addresses only the issue of vehicle driveability with gasoline/ethanol and gasoline/methanol/cosolvent blends. This paper does not examine driveability with gasoline/MTBE blends because there is less data available. There is current research in the area of gasoline/MTBE blends which has been sparked by recent interest in the fuels, and more data may be forthcoming.

Various programs have been conducted evaluating vehicle driveability with these blends and comparing it to that obtained with gasoline. Some of these programs include subjective evaluations of the performance of fleets of in-use vehicles. These evaluations provide information about the performance of the fuels under many driving situations. Other programs have been run with limited numbers of vehicles using more objective driveability tests with trained observers over controlled conditions. These tests do not cover all of the driving conditions encountered during in-use driving. This report summarizes the results of several testing programs. No attempt is made to reevaluate the conclusions of the individual studies.

1.1 Oxygen Content

Probably the most important factor in determining driveability of oxygenated fuels is the oxygen content of the fuel. This is usually expressed in weight percent of oxygen. Neat methanol has an oxygen content of 50% by weight, while that of ethanol is 35%. The maximum oxygen content of methanol blends is limited to 3.5% and 3.7% by weight under the EPA waiver decisions for Oxinol and the DuPont waiver blend, respectively. Gasohol contains 3.7% oxygen by weight, because the ethanol content is specified at 10%. Thus, the volume percent of methanol is limited to 7.0% and ethanol 10%. However, in the case of Oxinol and the DuPont waiver blend, the methanol content is limited to 4.75% and 5% respectively, due to the addition of cosolvent alcohols. Cosolvent alcohols reduce the possibility of phase separation in the blend, and they help prevent problems related to materials compatibility. They are required for gasoline/methanol blends (in at least a 1:1 ratio for Oxinol and a 1:2 cosolvent/methanol ratio for the DuPont blend) for these and other reasons. Including the oxygen content of the cosolvent alcohols, the oxygen content of the gasoline/alcohol blend will frequently be close to if not equal to the 3.5% or 3.7% by weight limit.

Oxygen content is an important driveability factor because the presence of oxygen in the fuel makes the air/fuel mixture leaner than if the fuel consisted only of hydrocarbons. With oxygenated fuels there is more oxygen available to burn a given quantity of carbon and hydrogen. Also, the oxygen displaces some of the carbon and hydrogen in a given volume of the fuel. Since fuel metering systems are generally volumetric, less hydrogen and carbon are delivered to the cylinders during a given cycle, and the mixture is enleaned. Since an engine usually operates best within a certain narrow range of air/fuel mixtures, anything that puts the air/fuel mixture outside that range (especially on the lean side) will tend to degrade the driveability. Therefore, the greater the oxygen content of the fuel, the leaner the mixture will be and the more likely it becomes that the mixture will be outside of the optimal range. As the mixture moves away from this optimal range, the driveability worsens. This phenomenon is especially important for older cars without closed loop control systems which adjust the air/fuel ratios to within the desired range. Many newer cars with closed loop control systems adjust air/fuel ratio for optimal operation of the engine and the catalytic converter. Driveability changes due to use of gasoline/alcohol blends should be less significant with these vehicles.

1.2 Volatility

Another fuel property that can influence driveability is volatility. Volatility affects the tendency of the fuel to evaporate enough to start a cold engine, its ability to vaporize fully and be distributed uniformly to all cylinders during and after warm-up, and the possibility during hot operation of producing vapor in the fuel metering system so that vapor lock occurs. Standard tests have been developed to measure properties which are related to these fuel qualities. Reid Vapor Pressure (RVP) is a measure of the vapor pressure at 100°F; the ASTM D-86 distillation procedure provides a temperature versus percent evaporated curve; and vapor/liquid ratio is measured as a function of fuel temperature. In addition, the heat of vaporization of a fuel provides an additional indication as to effects that are heat transfer dependent as opposed to equilibrium dependent.

A motor fuel with optimized volatility should evaporate just after it is metered into the intake stream. If it evaporates too early, then it may cause vapor lock or sluggish performance. If it evaporates too late, then it may cause uneven distribution among the cylinders and other conditions which would adversely affect driveability. Also, highly volatile fuel can excessively load the carbon canister, which can cause hot-starting problems when the canister is purged. Since different vehicles handle fuel in different ways, there is no single measure of volatility which correlates directly with the way fuel behaves in fuel systems.

Since the addition of alcohol to gasoline normally changes the fuel's volatility characteristics, it can have an effect on driveability. If blended with ordinary gasoline (splash blended), both ethanol and methanol will raise the RVP and increase the percent evaporated in the 140 - 200°F range. The effect on RVP is more pronounced with methanol blends. If the RVP of the base gasoline is adjusted to compensate for this increase by removing or leaving out light ends (those hydrocarbons which evaporate at lower temperatures, such as butanes and possibly pentanes), then the blend RVP can be held constant or increase only slightly. The addition of cosolvents can also reduce the effect of ethanol and methanol on RVP. However, the higher temperature volatility characteristics will still be different from those of typical gasoline because most of the alcohol evaporates within a relatively narrow temperature range. Special formulation of the base gasoline can negate this effect, but that is not considered necessary or economically feasible for most purposes. The type and quantity of alcohol in the blend dictates the effort and expense that would be necessary to adjust the volatility in a given way.

1.3 Heat of Vaporization

The heat of vaporization is the quantity of heat required to vaporize a given quantity of fuel. This heat is absorbed from the surrounding air and engine components thus having a cooling effect on them. Alcohols have a higher heat of vaporization than gasoline and, therefore, require more heat to vaporize as shown by the figures below.

Heat of Vaporization:	Gasoline	940 BTU/gallon
	Ethanol	2600 BTU/gallon
	Methanol	3320 BTU/gallon

Any possible problems related to this difference would most likely show up as difficulties in starting a cold engine or keeping it running once it is started. The standard ASTM fuel volatility tests mentioned above do not address this fuel property since they simply provide as much heat as necessary to achieve the required temperatures for fuel distillation or vapor formation.

1.4 Octane

Another driveability-related fuel property that is affected by alcohols is octane. Alcohols raise octane when added to gasoline, so the degree of engine knock experienced with gasoline/alcohol blends will tend to be less than that with a base gasoline of lower octane. However, some concern has been expressed[1] that the difference between research and motor octanes (known as the sensitivity of a fuel) may be larger for alcohols than for hydrocarbon compounds typically present in gasoline. Gasoline is frequently blended for an acceptable average of research and motor octanes (the "pump" octane, which equals [research + motor octane]/2), so the motor octane of the gasoline/alcohol blend may be lower than that of a hydrocarbon only fuel of the same pump octane rating. A low motor octane can result in engine knock especially under high speed or load conditions. Thus, use of gasoline/alcohol blends could result in some engine knock not experienced with gasoline. Knocking under conditions of high speed and load can lead to catastrophic failure of the engine[2]. However, other components commonly used in gasoline, such as toluene and xylene, have sensitivities as high as alcohols[3]. Some data are available indicating that the sensitivity of gasoline/alcohol blends may be somewhat more than that of gasoline itself[4] and other data indicate[3] that this situation may not occur.

1.5 Intake System Deposits

Deposits in the intake system can affect driveability, as well as fuel economy and emissions. Their formation is affected by fuel composition, engine condition, and vehicle use pattern. Deposits can accumulate anywhere from the carburetor to the intake valves, and they can restrict air flow, clog vacuum hoses, change swirl patterns, and otherwise interfere with devices in the intake system.

Some gasolines include detergent additives in order to minimize the accumulation of these deposits near the beginning of the intake system. These additives may not inhibit deposits forming farther downstream near the EGR duct or the intake valves. Other additives, such as carrier oils may serve to carry the deposit-forming materials into the cylinder, where they may be burned or exhausted. Of interest in this report is how the use of blended fuels can affect the formation of deposits in the intake system.

1.6 Other Parameters

There are many other factors which can affect the outcome of driveability tests, such as base gasoline composition, additives to prevent corrosion and phase separation (other than cosolvent alcohols), and specific points on the distillation curve of fuels. These parameters are useful in interpreting the results of individual test programs. However, it is beyond the scope of this report to examine them in detail for each study.

2.0 DRIVEABILITY TESTING PROGRAMS

Many organizations have conducted driveability testing programs. This section will summarize some of these programs. The smallest of the programs evaluated the performance of five vehicles, while the largest included several hundred. The programs generally did not evaluate driveability in the same way. Some of the smaller programs included controlled tests that were developed by the Coordinating Research Council, Inc. These tests involve drivers trained in the evaluation of driveability problems, as well as specified driving procedures. The larger programs were conducted with in-use fleets, so they were generally not able to conduct the controlled driveability tests. The evaluations that were produced by these programs are the result of longer term use under normal operating conditions, often over the course of more than a year.

2.1 Fleet Testing Programs

Southwest Research Institute conducted a variety of fleet tests over five and a half years as part of the U.S. Department of Energy's Project for Reliability Fleet Testing of Alcohol/ Gasoline Blends[5]. Most of the individual fleets participated in this program for approximately one year. These fleet tests were conducted in several geographic locations using four different gasoline/alcohol blends. The fuels were gasohol (apparently a splash blend with 10% by volume of anhydrous ethanol), a volatility controlled ethanol blend (10% by volume), Oxinol, and a 4.2% methanol blend which included 2.1% ethanol and 2.1% tertiary butyl alcohol as cosolvents. The tests were conducted under normal operating conditions with established fleet operators. A total of 552 vehicles accumulated 6,643,936 miles over the course of the program. Of these, 218 vehicles were operated on unleaded gasoline as experimental controls. The following fleets with a total of 264 vehicles participated in the driveability portion of this project: Contra Costa County, CA; Tennessee Valley Authority (two separate fleets); the State of New Jersey; the State of Minnesota; U.S. Border Patrol in El Paso, TX; and Southwest Research Institute. Vehicles in Contra Costa County were tested with two blended fuels (gasohol and a gasoline/methanol/ TBA blend); the other fleets were tested with only one blend.

The report includes analyses of the differences in driveability between the cars that were operated with blended fuels and the control vehicles in each fleet, as well as a composite analysis of the effects of gasohol on three of the fleets. The following problem areas were examined; starting, stalls during warmup, stalls in traffic, rough idling, hesitation, loss of power, pinging, and dieseling. Performance problems are rated in terms of the number of driver complaints divided by the number of total reports. In five of these areas, the blended fuels performed significantly worse than regular unleaded gasoline. Table 1 (reproduced from page 6-5 of the report) shows the results of significance tests of the measured differences in performance between the test and control vehicles within each fleet. Table 2 (reproduced from page 7-6 of the report) summarizes for three of the fleets the differences in performance between the vehicles which used gasohol and the vehicles which used gasoline.

Table 1. Summary of Driveability Tests Using Blends

Department of Energy/Southwest Research Institute

Table reproduced from page 6-5 of Reference 5.

FLEET	FUEL TYPE	CRANKING	STALLS WHILE STARTING	STALLS IN TRAFFIC	ROUGH IDLING	HESITATION	LOSS OF POWER	PINGING	DIESELING
CONTRA COSTA COUNTY	Gasohol	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TVA 1 & 2	Gasohol	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NS	NS
NEW JERSEY	Gasohol	NS	NS	<0.001	NS	<0.001	NS	<0.001	NS
CA. ENERGY COMM.									
Sacramento	M94.5 Vs EtOH	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001	NS	< 0.05
Los Angeles	Methanol (M94.5)	.05	NS	NS	.05	.05	.05	NS	NS
MINNESOTA	ET-2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NS
BORDER PATROL	ET-2	<0.025	<0.050	<0.001	<0.001	<0.005	<0.100	<0.100	NS
CONTRA COSTA COUNTY	Oxinol 50	<0.050	NS	NS	NS	<0.025	<0.005	NS	NS
SWRI	MeOH/EtOH/TBA	NS	<0.100	<0.001	<0.005	<0.001	< 0.010	<0.001	NS

NS Indicates no significance
* All entries are levels of significance

Table 2. Comparison of Driveability with Gasoline and Gasohol Department of Energy/Southwest Research Institute (Table reproduced from page 7-6 of Reference 5.)

COMPOSITE ANALYSIS - TENNESSEE VALLEY AUTHORITY, STATE OF NEW JERSEY AND CONTRA COSTA COUNTY

PERFORMANCE PROBLEMS	FREQUENCY* OF OCCURRENCE GASOLINE	FREQUENCY* OF OCCURRENCE GASOHOL	SIGNIFICANCE**
CRANKING	.0165	.0443	<0.001
STALLS WHILE STARTING	.0151	.0373	<0.001
STALLS IN TRAFFIC	.0039	.0209	<0.001
ROUGH IDLING	0.065	.0156	<0.001
HESITATION	.0106	.0406	<0.001
LOSS OF POWER	.0099	.0254	<0.001
PINGING	.0091	.0065	<0.025
DIESELING	.0047	.0017	<0.001

* Frequency = Total complaints/total reports, where gasohol total reports = 12,846 and gasohol total report = 11,743

** Value indicates significance level of test.

Gasohol performed significantly better than gasoline in the areas of rough idling, pinging, and dieseling, and significantly worse than gasoline in the other problem areas. Three fleets were used for the analysis listed in Table 2 (Contra Costa County, New Jersey, and the TVA fleets) totaling 108 vehicles from model years 1974-1981. Table 1 includes these fleets, as well as the Minnesota fleet, which had 60 1980-82 vehicles, the El Paso fleet, which had 52 1980-83 vehicles, the Contra Costa fleet operating on Oxinol, which had 30 1975-78 vehicles, and the Southwest Research Institute fleet, which had 14 1984 Ford Escorts. There were no reported incidences of vapor lock or problems with cold weather operation which were attributable to the use of the gasoline/alcohol blended fuels. These reports indicated that the differences in driveability with the gasoline/alcohol blends were statistically significant and definitely perceptible. But the reports did not necessarily indicate that the differences were large.

The Tennessee Valley Authority (TVA), in cooperation with ARCO, conducted a separate fleet test of 140 vehicles during 1983 and part of 1984[6]. This program tested a base fuel and three blended fuels. The blends included varying amounts of methanol and tertiary butyl alcohol to achieve oxygen contents of 3.5%, 4%, and 5% by weight (4.75%, 6.0%, and 8.2% by volume of methanol). The volatility of these blends was not controlled. The fleet was divided into four groups, one for each fuel. One of the sub-fleets used gasoline during the entire test period. The other fleets used blended fuels roughly half of the time; gasoline was used the rest of the time to allow evaluation of the drivers' responses with the same vehicles. Drivers recorded performance information on a daily basis during the test. Driveability was observed by recording the number and severity of occurrences of specific driveability problems. These were hard starting, rough idle, stalls during idle, stalls during driving, hesitation, backfire, dieseling, and knock. The data were analyzed separately for the four seasons. The analyses of these data showed no significant differences between the test and base phase for any of the fuels tested, except for the 3.5% and 5% oxygen blends during the spring phase of the program. However, in the case of the 3.5% oxygen blend, the report concludes that the observed differences are the result of factors other than oxygenate content. A few of the vehicles showed exceptional susceptibility to problems when fueled with the 5% oxygen fuel in the spring phase. The report concludes that the 3.5% and 4% oxygen fuels provide driveability equivalent to that of hydrocarbon-only fuels, and that the 5% oxygen fuel provides driveability equal to that of hydrocarbon-only fuels for most but not all vehicles.

Alberta Gas Chemicals, Ltd., the Ontario Ministry of Transportation and Communications, and Suncor Sunoco Group conducted tests beginning in 1982 on a fleet of 34 in-use vehicles in Canada[7]. The fuels used in this program contained 7% methanol and 3% isobutanol. These fuels were blended to meet the seasonal volatility specifications used by the supplier. The driveability testing portion of this program was conducted in four phases, using test criteria adapted from various CRC reports. The tests evaluated cold start, cold drive, warm start, and warm drive performance. The blended fuel gave worse driveability, but the report states that this difference is not statistically significant, and that the test drivers rated the fuel performance as acceptable.

In support of its waiver application for Oxinol, ARCO provided a wide range of driveability test data for Oxinol and other alcohol blends[8]. One program involved fleet testing of 150 employee-owned vehicles with fifty operating on each of a base gasoline, Oxinol, or gasohol. Results indicated that driveability of an Oxinol blend was equivalent to that of gasohol, and cold-engine performance was the only operating mode where these blends showed more operational problems than the base gasoline. A similar test program was conducted to evaluate cold weather operation using the same blends as well as a blend of 16% TBA. In this program all four fuels yielded equivalent driveability. A smaller scale testing program[9] examined vehicles in two fleets which had been using Oxinol for at least a year. One of these fleets consisted of eleven vehicles that were owned and operated by ARCO employees, while the other consisted of five matched pairs of vehicles (half of which used gasoline). The program examined the condition of the intake systems at the end of the period of Oxinol use, and found that the deposits in the Oxinol fueled vehicles' carburetors were typical of those which would be found in gasoline fueled vehicles of the same mileage.

American Methyl Corporation submitted some driveability test data along with its waiver application for Methyl-10[10]. This fuel consists of methanol, cosolvent alcohols and a proprietary additive blended with unleaded gasoline such that the final oxygen content is no more than 5.0% by weight. Fifteen 1974 - 1981 model year vehicles were evaluated by their owners over a six month period of operation on the test fuel. In general, it was found that older vehicles had less tolerance for oxygenates, and closed loop emission control systems on newer vehicles were found to alleviate most driveability concerns.

Ashland Oil Company conducted two short duration fleet tests (approximately 90 days each) of 1% and 2% methanol blends[11]. Eighteen vehicles were evaluated with the 1% blend, and four vehicles were evaluated with the 2% blend. For the 1% blend each of the drivers of the test vehicles were interviewed regarding their experience with the fuel. Comments ranged from neutral to positive. The comment most heard was a decrease in pinging when the cars began the test. Other comments noted improved fuel economy or improved acceleration. One vehicle with electronic fuel injection experienced hot start problems early in the test. No other problems were noted. For the 2% blend one vehicle experienced no significant change in startability, but there was a slight intermittent change in hot startability. A decrease in part-throttle knock intensity was the only significant difference noted with this vehicle using the test fuel. Another vehicle experienced more significant hot start problems, which may have been related to the use of fuel injection.

The Bank of America has conducted fleet tests with a variety of blends[12]. One program involved testing 67 unmodified vehicles fueled with blends of up to 8% methanol. Driveability was measured on the basis of starting, warm-up, idling, cruise, power (acceleration), and shutdown performance with drivers who did not know which fuel they were using. Vehicles without closed loop control systems experienced decreasing driveability with increasing oxygen content, but vehicles with closed loop systems maintained comparable driveability to gasoline even with 8% methanol fuel.

The TVA has also participated in a program of more controlled driveability testing, using the Driveability Test Procedure developed by the Coordinating Research Council (CRC)[13]. The tests were conducted on sixteen 1983 and 1984 model year vehicles which were leased from local car rental agencies. These cars had odometer mileages in the range of 500 to 15,000. The program tested five fuels; a base fuel from which the blends were developed, a splash blend of 10% Oxinol, a blend of 10% Oxinol with the RVP adjusted to within 0.5 psi of that of the base gasoline, a blend of 10% Oxinol with a reformate added to match the distillation curve of the base gasoline as closely as practical, and a splash blend of 10% ethanol. The report notes that the last of these reflected the characteristics of many commercially available gasohol blends. The report concludes that the different fuels did not affect cold-start driveability of the vehicles either as a group or when they are stratified by fuel system or emission control system.

The Coordinating Research Council conducted extensive tests on fourteen cars from the 1980 model year[14,15]. The driveability portion of these tests consisted of the CRC Intermediate Temperature Cold Start and Driveability Test, and the CRC Vapor Lock Test. These tests were conducted in two phases; phase one included ethanol blends, and phase two included methanol and methanol/cosolvent blends. The vehicles tested in this program represented a mix of emission control and fuel systems available in 1980; two had fuel injection, the rest had carburetors; seven had closed loop emission control systems calibrated to 1980 California emission standards, and seven had open loop systems calibrated to 1980 Federal emission standards. Only ten of the vehicles were tested in phase two, due to funding constraints. The following fuels were included in phase one of the program; a base fuel, a splash blend of 10% ethanol, a blend of 10% ethanol adjusted to match the RVP of the base fuel, and a blend of 10% ethanol adjusted to match the RVP and percent evaporated at 158°F of the base fuel. The blends had significantly worse driveability than the base fuel. In its discussion of the driveability data, the report states that the driveability is probably adversely affected by the leaning effect of the blends, and that increased volatility seems to improve driveability. The blends also showed a higher tendency to vapor lock than the base fuel. The tendency to vapor lock increased as the percent evaporated at 158°F increased. In the second Phase of the program, six fuels were tested; a base fuel (not the same as, but very similar to that in the first phase), a blend of 3.8% methanol, a blend of 3.3% methanol and 1.1% isobutanol, a blend of 10.0% methanol, a blend of 8.8% methanol and 2.9% isobutanol, and a blend of 14.0% methanol and 2.0% isobutanol. As with the phase one fuels, driveability with the blends was significantly worse than that with the base fuel. The report states that the driveability degradation seems to be related to the oxygen content of the fuel, and that the presence of cosolvent had no effect.

Mobil Research and Development Corporation conducted a number of driveability test programs comparing Oxinol blends to gasolines[16]. The first of these involved six 1983 cars tested with gasoline, a matched distillation Oxinol blend, and a lower volatility gasoline. Tests were conducted under temperature controlled conditions, at 60, 45, and 25°F. The cold start and driveability demerits for the Oxinol blend were 50 - 100% greater than the matched gasoline and roughly equivalent to the lower volatility gasoline. A second program using fifteen 1981-1983 cars and a consumer-type driveability test determined the cold start driveability at temperatures ranging from 0 - 60°F. A 12.5 psi RVP gasoline was best with 6% unacceptable trips, followed by a 14.8 RVP Oxinol blend with

9%, and a 9.8 RVP gasoline with 10% unacceptable trips. It is interesting to note that the blend averaged only half as many stalls on start-up as the 12.5 RVP gasoline. A similar study used ten 1984 cars at 60 - 95°F with both cold and hot start evaluations. The Oxinol blend fuel had RVP and distillation properties between those of the two test gasolines (11.3 and 11.8 psi RVP). The cold start results showed the percent of unacceptable trips with the blend to fall between the two gasolines. Under hot start conditions, however, the blend had a much greater percentage of stalls on start-up than either of the gasolines, and therefore, a greater percentage of unacceptable driveability (14% versus 0-4%).

Esso Petroleum Canada conducted a program in the summer of 1984 to compare a base gasoline with an Oxinol blend[17]. In this program two similar 30 car fleets represented the 1977-1984 model year Canadian car population. The program was followed in winter/spring 1985 with another program which included two 25 car fleets to represent 1980-1985 Canadian cars fueled with a winter grade gasoline, Oxinol blend or 10% MTBE blend. The summer Oxinol blend resulted in roughly twice as many complaints as the corresponding gasoline, including hard starting, rough idling, and sluggishness. For the winter fuels the Oxinol blend did not have any significant effect on start-up or idling, but there were roughly three times as many complaints of sluggishness relative to the gasoline. The MTBE had no significant effect on driveability.

From September 1983 to September 1984, Texaco conducted a one year test using 200 1976-1983 model year domestic vehicles with gasoline and two blends of 6% methanol and 2% TBA; one with RVP equal to the gasoline and one with RVP of 1.0-1.5 psi higher. The volatility of the base gasoline used to prepare the blends was adjusted to provide good warming-up performance when blended with the alcohols. The pump octane ratings of the blends were slightly higher than that of the gasoline. Vehicles operated 1/3 of the time on each of the three fuels. The program was designed to allow analysis of the effects of ambient temperature, warming-up driveability, warmed-up driveability, and knock. The warming-up driveability of all three fuels was roughly equivalent; the warmed-up driveability of the blends was lower. The report states that midrange volatility might be a factor which caused this degradation. No cases of vapor lock occurred, even with the higher RVP blend. The knock performance of the alcohol blends was slightly better than that of the gasoline, reflecting their slightly higher octane ratings.

3.0 SMALLER TESTING PROGRAMS (10 or Fewer Vehicles)

General Motors Research Laboratories conducted driveability tests using methanol and methanol/cosolvent blends[19]. Six 1983 and 1984 GM cars chosen to represent a mix of fuel systems were tested on five different fuel blends; a base fuel, a blend with 9.5% Oxinol, a blend with 8.2% methanol and 2.7% TBA, a blend with 3% methanol, and a blend with 7% methanol. Two versions of each of these blends were used, one to fit ASTM class C specifications, and one for class D. The fuels were tested with a modified version of the CRC hot-weather driveability and vapor lock procedure. Statistical analysis of the driveability data showed that the volatility class of the fuel was the most significant fuel-related factor in determining the driveability of these cars, and that the alcohol content was not as important. It was noted though that an isolated problem with fuel foaming occurred on one of the carbureted vehicles with a blended fuel containing 8.2% methanol and 2.7% TBA. Fuel foaming is apparently an unusual phenomenon involving formation of a gasoline foam in the carburetor bowl which results in excessively rich operation (less than 11.7:1 air:fuel ratio). It is not evaluated in conventional driveability tests. Formation of the gasoline foam is caused in part by excess fuel volatility. Intuitively, most fuel injected vehicles should be less susceptible to the problems of foaming and vapor lock, because the high pressures in the metering system prevent the fuel from vaporizing before it is added to the intake stream. Low pressure systems, which are less common than the high pressure systems, would have less of this resistance.

General Motors also conducted tests on five 1980 - 1981 model year GM cars, using three different fuels; a base (Indolene), a splash blend of 10% alcohol, and another with 18% alcohol[20]. The alcohol used was a 2:1 mix of methanol and butanol. The study showed that driveability with the 10% blend was much worse than that with the base fuel. Driveability with the 18% blend was not evaluated. The report cites the leaning effect of the alcohol, and the cooling of the intake manifold by the alcohol as reasons for the diminished driveability.

A presentation given by Sun Tech in 1983 shows a graph of total average demerits versus fuel oxygen content for eight 1980 vehicles using the CRC cold start and driveaway procedure with hydrocarbon-only, ethanol blend, and Oxinol blend fuels[21]. The curve has a significant, nearly linear positive slope indicating roughly equivalent deterioration of driveability for ethanol and methanol blends of equal oxygen content.

As part of the Tennessee Valley Authority program to evaluate gasoline/alcohol blends, seven 1983-1984 model year vehicles were evaluated for driveability using a cold start followed by 3.6 miles of driving through various maneuvers[22]. Five of the test vehicles were carbureted and two had throttle body fuel injection, and all vehicles were tested by a single trained driver. The fuels included a base gasoline, a 10% methanol blend, a 5% methanol/3.2% ethanol blend, and a 5% methanol/6.6% ethanol blend. Each vehicle/fuel combination was tested in duplicate. The tests indicated that the driveability of methanol blends was independent of the cosolvent used. The vehicle-to-vehicle variation was greater than any variation associated with different oxygen levels. While some vehicles performed poorly with methanol blends, they also performed relatively poorly with the base gasoline.

Texaco conducted a 50,000 mile testing program with six vehicles from the 1982 model year[23]. Three of these used a blend of 6%/2% methanol/TBA blend, while the others used gasoline only. Both fuels contained a detergent additive; the blended fuel contained 50% more. The only substantial difference found on examination of the two groups was the cleanliness of the intake valves. The cars which used blended fuel had heavy deposits on the intake valves, while those which used gasoline had much cleaner valves. The quantity of the deposits varied from cylinder to cylinder within each of the cars that used the blend. The report makes no determination as to whether the greater concentration of detergent in the blended fuel affected the formation of deposits.

VW has reported that greater detergent levels are needed to ensure that deposits do not build up in the intake manifold and carburetor[24]. Also, greater alcohol levels require greater amounts of detergent. The report does not discuss deposits on the intake valves, and it only discusses results of testing with gasoline/methanol blends.

Ashland Petroleum Company examined gasohol performance in dynamometer and in-use tests[25]. Three pairs of cars and some light trucks were used. One pair of vehicles was run on dynamometers for a 50000 mile test which examined lubricant performance, emissions, driveability, and other performance criteria. One vehicle was fueled with regular unleaded gasoline, and the other with a 10% ethanol blend. This test found little or no difference between the two vehicles in the fuel-related areas of comparison, including fuel economy, driveability, and deposits in the intake and combustion chamber. The other vehicles used in this testing program were tested in-use under less controlled conditions. Driveability was evaluated in formal reports by the drivers. The report concludes, based on the results of all of these tests, that driveability is not affected by the addition of ethanol.

4.0 Conclusions

As a general observation, the driveability of many vehicles on low level alcohol blends appears to be roughly equivalent to that of gasoline. However, there are indications of problems with some vehicles and certain operating conditions. These problems seem to occur less on vehicles with fuel injection and closed-loop fuel control systems which are more prevalent in recent model years. These problems seem to occur somewhat more on vehicles with carburetors especially those without feed-back to control air:fuel ratio. While driveability problems of the type discussed below are noted more with blends than with gasoline, it is not clear that the problems would be serious and/or objectionable, just that they would be perceptible to some degree. Nevertheless, the possibility of some increased driveability complaints due to increased use of gasoline/alcohol blends cannot be ruled out, although such complaints may not be numerous.

4.1 Oxygen Content

The closer a vehicle is to its lean operating limit with gasoline, the less fuel oxygen it will be able to tolerate before experiencing lean mixture driveability problems such as hesitation and some loss of power as noted in the Department of Energy project.

It appears that the richer a vehicle operates on gasoline (whether due to carburetor adjustment or high altitude operation, although no driveability tests have been run with gasoline/alcohol blends at high altitude) the more fuel oxygen it should be able to tolerate before experiencing any deterioration of driveability. (Any vehicles which operate excessively rich on gasoline may even experience improvements in driveability with oxygenated fuels.)

As mentioned above, closed loop fuel metering systems can alleviate most if not all of the normal driveability problems that can be associated with the mixture enleanment of oxygenated fuels, up to the adjustment limits of the system.

Without closed loop systems, increasing fuel oxygen content can be expected to increase the incidence of driveability problems.

4.2 Excessive Fuel Volatility

For blends the higher volatility in the 140 - 200°F range can result in increased driveability problems due to increased cases of vapor lock, fuel foaming, and hot-starting problems.

Also, a loss of power in traffic is often noted before vapor lock occurs. Such problems would be more likely to occur in high altitude areas. Blends showed an increased tendency to vapor lock in the CRC vapor lock procedure than gasoline, but vapor lock was not specifically found to be a problem in the studies of in-use vehicles. Some of the in-use studies did find increased hot-starting problems.

These problems can be mitigated somewhat by keeping blends in compliance with ASTM volatility recommendations. Additional control of volatility, such as maintaining the percent evaporated at some midrange point in the distillation curve equal to that of typical gasolines or additional reductions in RVP, might help more. Adjusting the entire distillation curve to be equal to that of typical gasolines would help quite a bit. It is not known, however, how such an adjustment would interact with the high heat of vaporization (of alcohols) or other parameters to affect driveability under other conditions, such as cold starting. The high cost of an adjustment such as this, as well as other factors, would make it unlikely to occur in actual practice.

4.3 Heat of Vaporization (cold starting)

Ethanol and methanol require approximately three times as much heat to vaporize as does gasoline. Under certain conditions this can make it a little harder to start and keep a cold engine running with blends that contain these alcohols. However, a high heat of vaporization might reduce somewhat the likelihood of vapor lock by cooling the fuel system.

4.4 Octane (knock, dieseling)

Since methanol and ethanol increase the pump octane rating of blended fuels, there is a tendency for blends to reduce incidences of knock and dieseling (run-on) relative to the base gasoline. Research octane may benefit more from alcohols than motor octane, so under certain operating conditions where motor octane is important (e.g., high load) there may be no effective octane benefit from the alcohol. However, the data available on this point do not conclusively indicate whether the increased sensitivity of the blended fuels over gasoline would pose a problem.

4.5 Intake System Deposits

Increased amounts of deposits, especially on the intake valves, have been reported in some studies[26], while others have indicated that there is no such increase. It is possible that the differences may be due to variations in the quantity of detergents used in the fuels. Evidence is not available to conclusively resolve this issue.

4.6 Other Parameters

Fuel additives are mentioned in many of the reports as being crucial to the successful operation of a vehicle with a gasoline/alcohol blend. These additives are formulated to inhibit corrosion, prevent the gasoline and alcohol from separating, and help clean fuel system parts. Their effect on driveability is less direct than the other fuel properties, and their value becomes more apparent when examining the issue of materials compatibility.

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