

FINAL REPORT

PERFORMANCE OF VEHICLES AND EQUIPMENT INVOLVED IN
THE USE OF GASOHOL

by

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SUMMARY

A 1-year fleet test in which 130,000 gal. of gasohol were prepared and used was conducted in the Charlottesville-Culpeper area. The handling and storage of the fuel was monitored, and fuel consumption and maintenance records were maintained on 95 Department vehicles (primarily 1/2-ton pickup trucks and 3-ton dump trucks) that operated a total of 1.5 million miles on gasoline and gasohol.

The study determined that gasohol can be satisfactorily used to reduce gasoline consumption by from 7% to 8%. Special attention must be directed, however, to filter plugging, water contamination, evaporative emissions, and equipment that may deteriorate prematurely due to the presence of alcohol in the fuel. In general, the drivers of the vehicles monitored in the study perceived gasohol to be comparable to gasoline, with the exception that gasohol reduced the engine ping often noted from engines operating on low octane, no-lead gasoline.

Gasohol reduces exhaust emissions but increases evaporative emissions; therefore, no overall benefit in air quality is achieved from its use.

At today's prices, the use of gasohol would increase fuel costs by from 11% to 12%, but it is anticipated that the cost of gasohol relative to that of gasoline will decrease as more alcohol becomes available and as the price of gasoline continues to increase.

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INTRODUCTION

Gasohol is most commonly defined as a mixture of 10% by volume of 200-proof grain alcohol (ethanol) and 90% by volume of commercial grade, no-lead gasoline. The fuel is being offered at an increasing number of commercial service stations in various parts of the country, including Virginia. Other versions of gasohol that have been or are now being promoted and marketed to a more limited degree include mixtures of 12%, 15%, and 20% ethanol (200-proof) and no-lead gasoline, gasohol prepared with similar percentages of 192-proof ethanol, and a mixture consisting of 5% wood alcohol (methanol) and 95% no-lead gasoline.⁽¹⁾ Unless noted, this report deals with the current most common definition of gasohol, which originated with the fleet test conducted by Scheller in Nebraska beginning in December 1974.⁽²⁾

The idea of using alcohol as motor vehicle fuel is as old as the internal combustion engine. However, because of the relative abundance and low price of gasoline, the large-scale production and use of alcoholic fuels have not been practical. While a significant amount of alcohol was used as motor vehicle fuel during World War II because of the shortage of gasoline, interest in this use of alcohol subsided until the OPEC oil embargo brought a sudden realization of the dependence of the United States on foreign oil imports. With the rise in gasoline prices since the 1973 embargo, the economics of producing and using alcohol have become more attractive.

Additional interest in alcohol production stems from the gradual phasing out of lead as a gasoline additive and the consequent need for acceptable, economical, and energy efficient alternative additives capable of maintaining satisfactory octane levels in no-lead gasoline. Recent interest in alcohol production also stems from the clean-burning characteristics of alcohol and the anticipated beneficial effect a move toward alcohol fuels might have on efforts to reduce the level of harmful emissions

produced by motor vehicles. But the major incentive for alcohol production comes from the 1978 National Energy Act, in which the U. S. Congress granted a 40¢ per gallon subsidy for alcohol derived from renewable resources and used to make gasohol. The 40¢ per gallon subsidy results from the exemption of gasohol from the 4¢ per gallon federal tax on motor fuel. While a majority of the members of Congress consider the subsidy to be necessary to make gasohol competitive with gasoline at the commercial pump, many feel that the elimination of the tax will have a devastating impact on a major revenue source for the nation's highway program.⁽³⁾ The Act also provides for loans, loan guarantees, and direct grants for the construction of alcohol plants, and an additional 10% investment tax credit for alcohol plants that don't use oil or natural gas in the production of alcohol.⁽⁴⁾

According to the National Alcohol Fuels Commission, as many as 300 new alcohol fuel plants are being planned. One of these is a 50-million-gallon-per-year plant being constructed in Sioux City, Iowa, at a cost of \$47 million for Alcohols, Inc. of Charlottesville, Virginia.⁽⁵⁾ According to Virginia Agriculture Commissioner S. Mason Carbaugh, production facilities now in the planning stages in Virginia have the potential to produce approximately 228 million gal. of alcohol a year by 1983.⁽⁶⁾ In the meantime, as reported in the Engineering News Record article cited in reference 5, the Department of Energy and the Department of Agriculture are participating in a joint program aimed at substituting gasohol for 10% of the U. S. gasoline needs by 1990. Clearly, increased supplies of alcohol and gasohol are going to be available in the near future.

Many individuals and organizations are conducting fleet tests with gasohol. Although almost no one questions that gasohol can be used in an unmodified engine, there are great debates as to how well it works. Some consider gasohol to be a highly desirable, clean-burning, homegrown fuel that can reduce the nation's dependence on foreign oil; others consider it to be an energy inefficient fuel that detracts from the development of more promising alternatives such as methanol derived from coal and gasoline derived from coal and oil shale. The principal issue is the amount of energy required to produce ethanol for use in gasohol, and how this compares with the energy requirements for the production of other alternatives to gasoline from petroleum. The debate will likely continue for the next 10 years, or as long as it takes to get some of the liquid alternatives to petroleum into the transportation system so that comparisons based on empirical data rather than theory can be made.

In the context of considering ways to reduce gasoline consumption the Virginia Highway and Transportation Research Council began to consider the use of alcoholic fuels in 1975.⁽⁷⁾ The results of an 18-month investigation of blends of wood alcohol and gasoline were issued in November 1977,⁽⁸⁾ and a report on the Nebraska gasohol experience was prepared in February 1979.⁽⁹⁾

In the spring of 1979, confronted with spot shortages of gasoline and with gasoline rationing in Virginia, Attorney-General Coleman urged that all state vehicles be run on gasohol.⁽¹⁰⁾ Recognizing that there was a significant likelihood that some decisions concerning the use of gasohol in state vehicles would have to be made in the near future, and that a short-term fleet test would be desirable to help identify significant problems and to provide information necessary for cost-effective decisions, the Research Council initiated a fleet test of gasohol in June 1979.

PURPOSE AND SCOPE

The study was undertaken, at the request of the Equipment Division of the Virginia Department of Highways and Transportation, for the purpose of collecting the practical and technical information needed for a cost-effective and satisfactory transition from the use of no-lead gasoline to the use of gasohol.

The basic tasks were -

1. to identify and evaluate any significant factors noted in handling, storing, and dispensing the fuel;
2. to identify and evaluate the significance of factors that can result in a deterioration or improvement in the performance of all types of vehicles and equipment ranging from lawn mowers to 3-ton dump trucks; and
3. to compare the performance of vehicles and equipment operating on gasohol with that of vehicles and equipment operating on no-lead gasoline.

It must be recognized that any fleet test has its limitations and that the results of the test reported upon here are specifically applicable only to the vehicles, equipment, fuel, and conditions encountered.

Gasohol was used over a period of 8 months in all types of equipment ranging from lawn mowers to 3-ton dump trucks, and when the results of this full-scale, short-term use of gasohol are considered along with the results of tests conducted by others, it is believed that a reasonably accurate assessment of what to expect from the short-term use of gasohol can be had. Although some prediction of what to expect over the long-term can be made from the study, a much longer period of evaluation is required to develop significant findings applicable to the long-term.

METHODOLOGY

The 1-year fleet test was initiated June 1, 1979, and completed May 31, 1980. During the test, records on fuel and oil consumption and maintenance were maintained by the principal operators of the vehicles and equipment. Included in the test were 44 three-ton dump trucks, 51 lightweight vehicles (predominately 1/2-ton Dodge pickup trucks), and miscellaneous gasoline-powered equipment. The time spans of June through July 1979 and April through May 1980 were used as the control period and the 8 months from August 1979 through March 1980 served as the test period. During the control period all vehicles and equipment were operated on no-lead gasoline. During the test period the vehicles and equipment located at the Charlottesville residency, the Yancey Mills area headquarters, and the Boyds Tavern area headquarters were operated on gasohol, while the other vehicles and equipment involved in the fleet test and located at four other area headquarters in the Charlottesville area and at the Department's Culpeper residency and district headquarters continued to operate on no-lead gasoline. To provide comparisons of fuel consumed by vehicles operating on gasohol versus the fuel consumed by vehicles using no-lead gasoline during the test period, information obtained from the records maintained during the control period was used to pair vehicles and equipment according to similarities in type, age, odometer reading, and fuel consumption using gasoline. A total of 33 pairings were made. Equipment such as lawn mowers, generators, and tractor mowers were operated on gasohol during the test period but no comparative data were compiled.

At the end of each month, records on fuel and oil consumption and vehicle maintenance were forwarded to the principal investigator, who developed comparisons between the gasohol-powered vehicles and the gasoline-powered vehicles. The records were also used to identify an improvement or deterioration in vehicle performance. In addition to the monthly records, information on fuel consumption was obtained by placing 8 vehicles on a dynamometer where they were operated on both gasohol and gasoline. An infrared exhaust emission analyzer was used to determine how exhaust emissions for the two fuels compared. This analysis was made on emissions from 10 vehicles operating on gasohol and another 10 operating on gasoline. Also, samples of oil obtained from three pairs of vehicles were sent to the Fuels and Lubricants Division of the U. S. Army at Fort Belvoir, Virginia, where they were analyzed for metals content. General information was derived from the questionnaire completed by the drivers of the gasohol-powered vehicles when after the tests they were asked to comment on the performance of their vehicles.

With respect to the handling and storage of alcohol and gasohol, the proof of the alcohol was checked with a hydrometer after each of the two 6,500-gal. deliveries, and the alcohol content of the gasohol was determined by infrared spectrometry on a sample from each of the 27 deliveries of gasohol. The ASTM D-86 Distillation Tests and alcohol content determinations were conducted at Fort Belvoir on 12 samples of gasohol and 1 sample of gasoline used in the fleet test. Laboratory samples were prepared and allowed to evaporate so that comparative evaporative rates could be studied. Additional tests dealing with the water tolerance of gasohol were also conducted in the laboratory. The storage tanks were checked for water prior to introducing the gasohol and were checked for sludge for several months after the gasohol was added. Records were maintained on the quantities of fuel delivered and dispensed to vehicles so that storage losses could be monitored.

The results of the study are based on the monthly records maintained by the drivers, the dynamometer tests, the driver survey, the various laboratory tests, and the evaluation of handling and storage.

RESULTS

The results of the study are reported in four sections. The first describes the characteristics of no-lead gasoline, 200-proof ethanol, and gasohol. The second section tells how the fuels were handled and stored. The third and longest section deals with vehicle performance, the one aspect of gasohol usage about which there is considerable controversy. This section also deals with exhaust emissions because they are related to vehicle performance. The fourth section briefly covers the costs of the fuels, which are of obvious importance to any organization attempting to operate in a cost-effective manner. The next part of the report discusses the results reported in these four sections and relates them in a manner considered relevant to the operations of the Virginia Department of Highways and Transportation.

Fuel Characteristics

Properties

Properties of ethanol, gasoline, and gasohol that are of interest here are shown in Table 1. The principal difference in the fuels is that ethanol, and thus gasohol, contains oxygen while gasoline does not. Consequently, the amounts of air needed for the complete combustion of 1 lb. of fuel are 9.0 lb. for ethanol, 14.7 lb. for gasoline, and 14.1 lb. for gasohol. The oxygen in ethanol also affects its heating value, which is two-thirds that of an equal volume of gasoline; and, therefore, the value for gasohol is 3.4% lower than that for gasoline. Also, ethanol burns at a

Table 1. Properties of Ethanol, Gasoline, and Gasohol

<u>Property</u>	<u>Ethanol^a</u>	<u>Gasoline^a</u>	<u>Gasohol^b</u>
Formula	C_2H_5OH	$C_xH_{2x\pm}$	$C_xH_{2x\pm} + C_2H_5OH$
Stoichiometric air-fuel ratio (lb/lb)	9.0	14.7	14.1
Heating value (Btu/gal. at 68°F.)	75,670	115,400	111,427
Flammability limits (Volume percent)	4.3 - 19.0	1.4 - 7.6	1.4 - 19.0
Specific gravity at 60°F.	0.794	0.72 - 0.78	0.73 - 0.78
Boiling temperature	172	80 - 437	80 - 437
Flash point	55	- 45	- 45
Octane number research	111	91 ^c	95 ^d
Octane number (R + M)/2	102	87 ^c	90 ^d
Reid vapor pressure (psi) ^e	2.2	10.0	10.7

a Unless otherwise indicated, the numbers are courtesy of the API, reference 11.

b Based on properties of ethanol and gasoline.

c Novack, AMOCO.

d Estimated on the basis of references 12, 13, and 14.

e EPA and General Motors, references 13 and 14.

much wider range of fuel concentrations than gasoline, and its higher flammability limit would be expected to control the higher flammability limit for gasohol.

The octane number (antiknock quality) is an important property of automotive fuel in that it must be equal to or greater than the number determined by the manufacturer of a particular vehicle to be the lowest acceptable for satisfactory performance. The minimum acceptable octane for the vehicles involved in the study was 91 for the research method and 87 for the average of the research method and the motor method $[(R + M)/2]$.^{*} According to a representative of AMOCO,^{**} which supplied the no-lead gasoline used in the study, all the gasoline delivered during the study period had a research octane of 91 and an $(R + M)/2$ octane of 87. The addition of ethanol to gasoline increases the research octane by 3 to 5 numbers and the $(R + M)/2$ octane by 2 or 3 numbers, (12, 13, 14) and, therefore, it seems reasonable to assume that the research octane of the gasohol used in the fleet test conducted by the Research Council was 95 and the $(R + M)/2$ octane was 90.

Alcohol Content

Two-gallon samples of gasoline and gasohol were taken from the fueling areas used in the study for evaluation. A laboratory procedure, adapted from Ritchie and Kulawic,⁽¹⁵⁾ that uses an infrared spectrophotometer to compare samples of gasohol with standards prepared to have predetermined concentrations of alcohol was used to determine the alcohol content of the gasohol after each of the 27 deliveries. With the exceptions of the month of January, when the average alcohol content dropped to 9.1% because 1,700 gal. of gasoline were accidentally added to the storage tank at the Yancey Mills area headquarters, and the last 2 weeks of March, when a mixture consisting of 14.6% alcohol was deliberately made available at the Charlottesville residency, the average alcohol content was maintained at $10\% \pm 0.2\%$. With these two exceptions, all samples of gasohol were found to have an alcohol content of $10\% \pm 0.5\%$ as determined by a sampling and test procedure having a precision of $\pm 0.2\%$. During the first half of the test period, 12 samples of gasohol and 1 sample of gasoline were sent to the Fuels and Lubricants Division of the Department of the Army located at Fort Belvoir, Virginia. The gasohol samples were tested for alcohol content using a gas chromatograph method, and with two exceptions the results were comparable to those determined using an infrared spectrophotometer.

* Personal communication, Norman Nielsen of Chrysler Corporation, Detroit, Michigan, August 1980.

** Personal communication, Novack, AMOCO Terminal, Newington, Virginia, August 1980.

Vaporization

The ASTM D-86 distillation test is believed to provide a reasonable indication of the vaporization characteristics of automotive fuel. The data for the curves shown in Figure 1 were supplied by the Department of the Army based on samples of fuel taken in August 1979.* With the exception of slight seasonal changes, which are normal, the curves are similar for samples of gasohol taken at other times during the test period. It can be seen that the ends of the curves for gasoline and gasohol are similar. Close agreement at the lower end suggests that the Reid vapor pressure of the gasohol was not much different from that of the gasoline. Although Scheller reports the pressure of gasohol to be 0.2 psi less than that for no-lead gasoline, (16) the EPA shows it to be 0.7 psi higher, (17) the American Society of Petroleum Operations Engineers (ASPOE) reports it to be 0.9 psi higher, (18) and the American Petroleum Institute (API) suggests it is slightly more than 1 psi higher. (19) A high Reid vapor pressure is indicative of high evaporative losses.

A drop in the upper end of the distillation curve can increase the chances for vapor lock, and the API reports that studies with gasoline have shown that both the Reid vapor pressure and the fraction distilled below 160°F control the tendency to vapor lock. (20) Figure 1 shows that for the gasoline used by the Department of Highways and Transportation only 22% was distilled below 160°F, whereas for the gasohol the liquid volume distilled below 160°F increased to 42%. One might conclude that conditions nearly causing vapor lock with gasoline might cause vapor lock with gasohol. The greatest difference between gasohol and gasoline occurs between the 10% and 50% liquid volume distilled, as is shown in Figure 1. Scheller suggests that the depression in the gasoline curve associated with the addition of alcohol would cause improved performance and better starting in the winter months and more complete vaporization and better intake manifold distribution at all times. (21) On the other hand, the API suggests that the depression could cause vehicle operational problems because there would be a tendency for an unbalanced fuel distribution among the cylinders, (22) and, similarly, others suggest that the depression could cause poor fuel economy. (23)

* Personal communication, Maurice E. LePera, Fuels and Lubricants Division, Department of the Army, Fort Belvoir, Virginia, 1979.

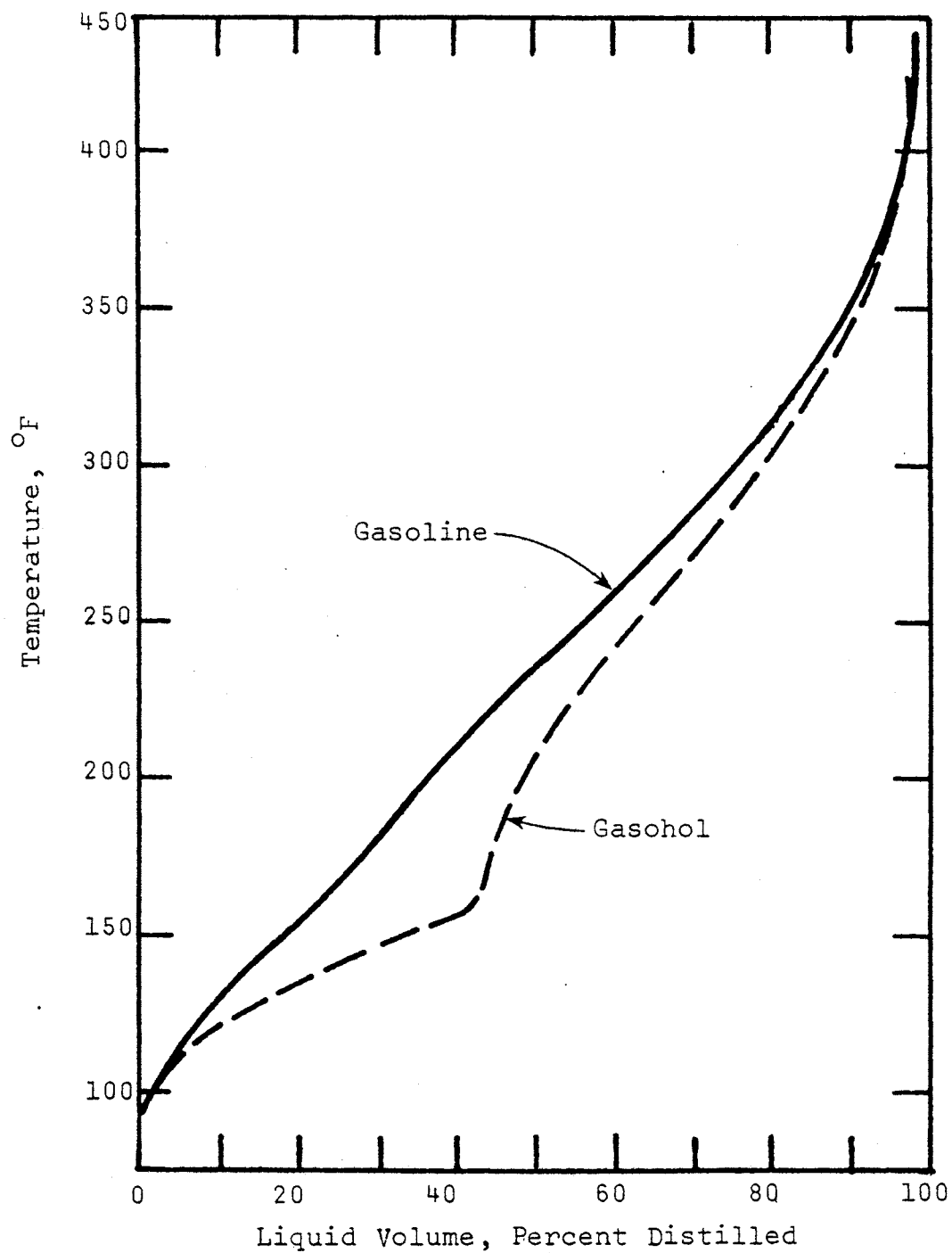


Figure 1. ASTM D-86 distillation results, August 1979.
Source of data: Department of the Army.

Handling and Storage of Fuels

Preparation of Gasohol

The Department of Highways and Transportation prepared its first gasohol on July 19, 1979, after receiving 6,500 gal. of 200-proof ethanol on July 18. Mar-Cam Industries, Inc. of Glenside, Pennsylvania, supplied the alcohol at a cost of \$1.71 per gallon. A second delivery at a cost of \$1.73 per gallon was received in October. According to Mar-Cam Industries, the alcohol was denatured in accordance with U. S. Treasury Department Formula #19, which prescribes that 4 gal. of methyl isobutyl ketone and 1 gal. of gasoline be added to 100 gal. of ethanol. The alcohol was stored in a new 10,000-gal., above ground, metal storage tank. A meter especially designed to dispense alcohol was installed on the tank. A 1-gal. sample of the alcohol was checked and found to have a proof in excess of 199 as determined with a hydrometer.

The procedure used to prepare the gasohol consisted of (1) filling each of four lockers on a new 6,500-gal. capacity, top-loading tank truck to 90% of capacity with AMOCO no-lead gasoline obtained from a 40,000-gal. capacity, above ground storage tank; (2) moving the truck a few feet to the tank containing the alcohol and adding to each locker an amount of alcohol equivalent to 10% of its capacity; (3) driving the tanker from Culpeper to one or more of the three fueling areas in the Charlottesville area, a distance of 50 to 60 miles; and (4) metering the gasohol into the underground storage tanks.

Recommendations for blending gasohol can be found in the literature. According to Fodge, (24) the recommended way to blend gasohol at both bottom-and top-loading terminals is to first add the alcohol and then the gasoline. Obviously, this sequence would provide more agitation for the alcohol than adding the alcohol last; however, the alcohol content determinations made on samples taken after each delivery indicated that adequate mixing was achieved. The agitation provided by the 50-to 60-mile trip and the fact that both fuels were at the same temperature when mixed likely ensured adequate mixing.

For vertical bulk storage and underground tank blending, Fodge recommends that the fuels be added in the following sequence: gasoline in bottom third, alcohol next, and top with remainder of gasoline. He recommends that the mixture be allowed to stand for 2 days and the bottom 3 in. be removed and added to no-lead gasoline. He recommends that the temperatures of the components be within 10°F of each other.

Preparation of Storage Tanks

The gasohol was delivered to three fueling areas in the vicinity of Charlottesville. One of the areas, the Charlottesville residency, has a 10,000-gal. tank that was installed 5 years previous to the beginning of the fleet test, and the Yancey Mills and Boyds Tavern area headquarters have 6,000-gal. tanks installed 7 and 9 years, respectively, before the test.

Prior to the first delivery of gasohol, these tanks were checked for water using a standard water paste. No water was noted at the residency but 8 gal. were removed from the tank at Yancey Mills and 15 gal. from the one at Boyds Tavern. The bottom of a 2,000-gal. tank located at the Keene area headquarters, which served as one of the fueling areas for the control vehicles, was found to contain 26 gal. of water. Although various figures can be found in the literature, it is believed that as little as 0.25% water in gasohol can initiate some separation. This is the amount of water found in gasohol prepared with 195-proof alcohol, or the amount of water that would be found in 6,500 gal. of gasohol prepared with 200-proof alcohol but added to a storage tank containing 16 gal. of water. Figure 2 shows separation curves for two temperatures and various alcohol proofs and aromatic contents for gasoline. (25)

Because of its highly adverse effects on gasohol, water obviously had to be removed from the storage tanks. According to a report by the U. S. Department of Energy, (26) approximately 30% of the commercial service station tanks included in a survey had 0.25% or more water when checked half-full, as did 85% of the bulk tanks. These findings can be assumed to provide a reasonable indication of the percentage of its tanks that the Department would have to remove water from prior to using them for the storage of gasohol. As a matter of practice, however, it would be necessary to check for water and remove undesirable quantities prior to adding gasohol to any tank. Unless, of course, there is an infiltration of water that would make a tank unacceptable for the storage of gasohol, the continued use of anhydrous gasohol would likely result in the storage system becoming anhydrous.

Cleaning Action of Alcohol in Gasohol

Gasohol prepared for the first delivery to each of the three fueling areas contained 12%, more or less, of alcohol to provide a 10% blend when added to the small amount of gasoline left in the tanks prior to adding the gasohol. The first problem was reported on July 30, just 4 days (2 workdays) after the gasohol was added to the tank at Boyds Tavern. The pump would not supply fuel because the filters were plugged. After changing the filters several times

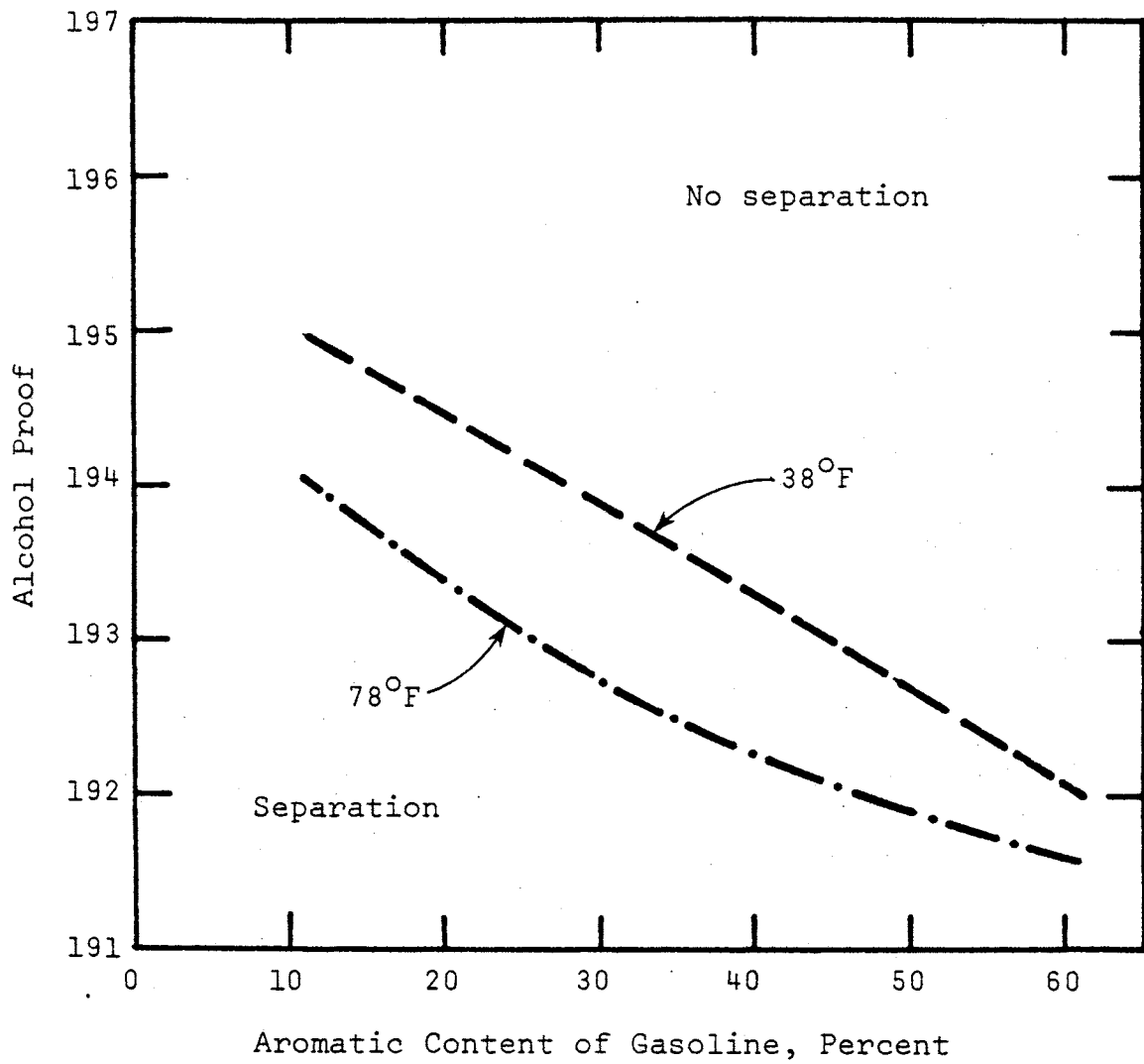


Figure 2. Water separation (after Fodge, reference 25).

the problem was not corrected. A sample of fuel removed from the bottom of the tank did not show a definite sludge bottom, but did reveal a significant amount of material in suspension. Excavating revealed that the tank was 2 in. lower at the suction end than at the fill end and sludge was being pulled through the filters. To eliminate the problem, the sludge was removed and 2 1/2 in. was cut from the end of the suction line. Because the tank had been installed incorrectly, all the water had not been removed from the tank prior to adding the gasohol and, consequently, a larger than usual sludge bottom of water and alcohol with suspended material was being dispensed. Unfortunately, the sludge entered the fuel tanks of some of the vehicles and caused problems with the filters.

A sample of fuel taken from the bottom of the tank at Yancey Mills 1 week after the first gasohol was delivered revealed 1 3/4 in., or approximately 25 gal., of sludge; and a sample of fuel taken from the bottom of the tank at the Charlottesville residency 17 days after the first gasohol was delivered revealed 2 in., or approximately 51 gal., of sludge. An analysis of the sludge removed from the tank at the residency revealed that it contained approximately 75% alcohol by volume. The remainder was believed to be gasoline, water, and miscellaneous suspended and dissolved materials likely removed from the walls of the storage tank by the solvent action of the alcohol in the gasohol. The sludge did not plug the filters at the residency or at Yancey Mills because it was below the level of the suction pipe.

When it was noted in the laboratory that the sludge would mix with unleaded gasoline and gasohol if properly agitated, no effort was made to remove it from the tanks at the residency and Yancey Mills. Since the tanks have drop tubes, sufficient agitation to mix the sludge was provided when the second loads of gasohol were added to the tanks. Samples subsequently removed from the bottom of the tanks revealed that the sludge was mixed with the fuel. Since 200-proof alcohol was being used in the gasohol, no further problems with sludge were encountered following the cleaning of the tanks.

The formation of sludge could be avoided by installing new tanks, an obviously uneconomical and unnecessary solution. Only in a case where a problem with water infiltration cannot be solved will it be necessary to install a new tank or take other corrective action.

Storage Evaporation

As discussed in the fuel characteristics section of the report, there is a strong probability that the vapor pressure of gasohol will be greater than the vapor pressure of the no-lead gasoline used to prepare it. Although Scheller reports no increase in Reid

vapor pressure with the addition of alcohol to gasoline, (27) the EPA reports an increase of 0.7 psi, (28) the ASPOE reports an increase of 0.9 psi, (29) and the API reports an increase of slightly more than 1 psi. (30) Because of the higher vapor pressure of gasohol, Fodge recommends that all gasohol storage tanks be equipped with a special P-V vent; more specifically, a Morrison Brothers #548A, 2 in. threaded, 16 oz. pressure, 1 oz. vacuum, #6 mesh screen vent. (31) A similar recommendation was made by Lyon in testimony before the House of Representatives on May 16, 1979, (32) but in recent conversations with the author Mr. Lyon indicated that a Morrison Brothers #748A costing approximately \$70 is the preferred vent.*

The results of above ground storage evaporation tests conducted at the Research Council are shown in Figure 3. The data are based on the average periodically determined weight of two 1-liter containers of gasoline, gasohol, and mixtures of gasoline and ethanol containing 20% and 30% ethanol. The containers were vented to the atmosphere by not securing the tops. Of particular significance are the following observations.

1. Greater losses occurred with all combinations of alcohol and gasoline, including the gasohol, than for the gasoline. This result supports the reports that the vapor pressure of a blend of alcohol and gasoline is greater than that of either gasoline or alcohol.
2. The major part of the difference in losses between gasoline and gasohol occurred during the first week of storage; thereafter, losses were similar.
3. Losses associated with the storage of alcohol were considerably less than those for gasoline or combinations of gasoline and alcohol. This result could be expected when it is remembered that the vapor pressure of gasoline is 5 to 10 times greater than that of alcohol.

The amount of evaporation exhibited by gasohol relative to gasoline as indicated in Figure 3 is supported by the results of evaporative emissions tests conducted on 11 vehicles by the EPA. (33) The EPA tests showed a 60% to 70% increase in evaporative emissions for gasohol prepared by adding 10% ethanol to a commercial gasoline as compared to the gasoline. In Figure 3, the average percent weight change for 1 and 2 weeks in storage is 67% greater for gasohol than for gasoline.

* Personal communication, Harry B. Lyon, August 1980.

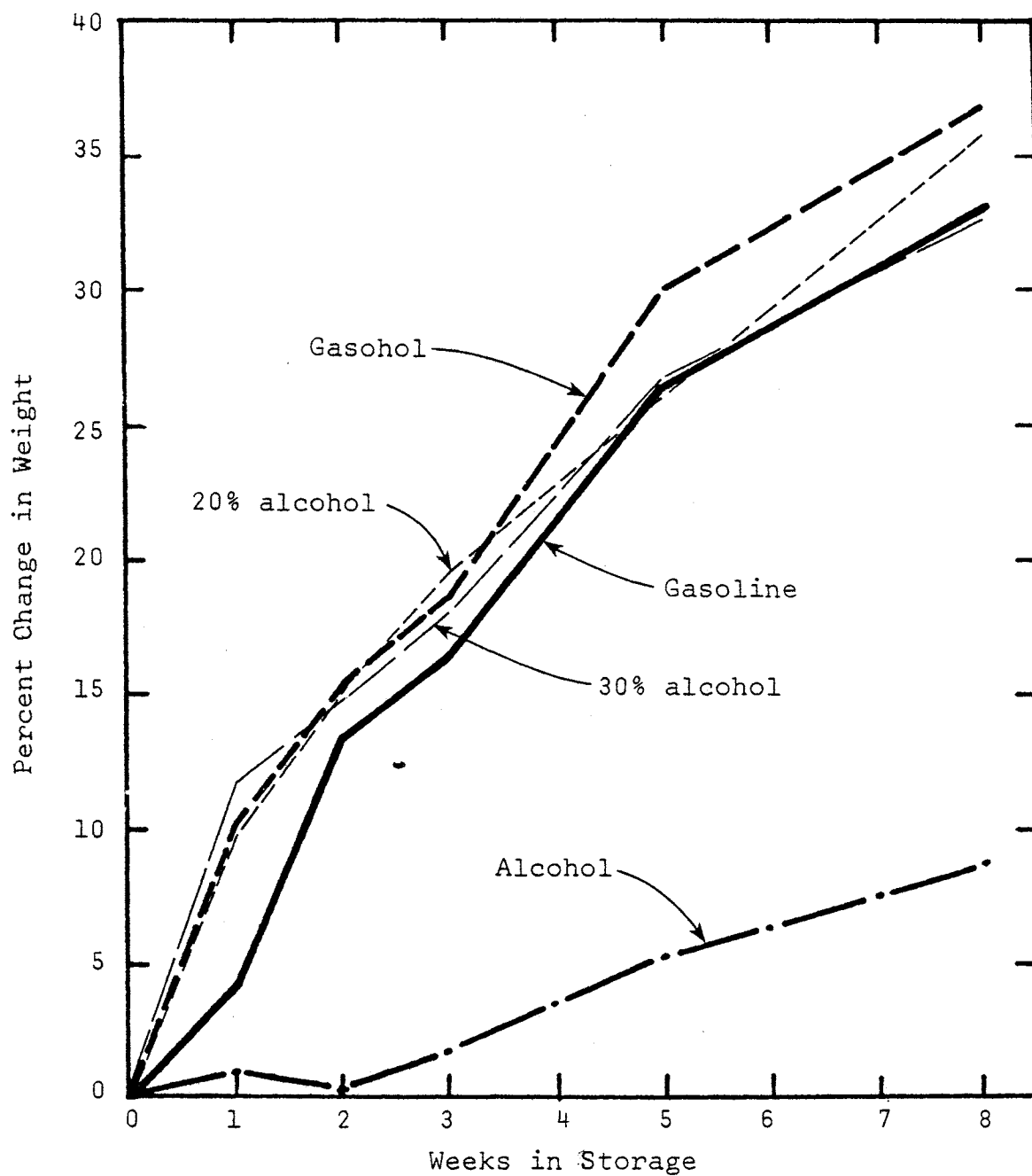


Figure 3. Storage evaporation.

Information is available for estimating the losses that occur during the storage of gasoline.⁽³⁴⁾ For underground tanks, a standing loss of 1 lb. of hydrocarbons per 1,000 gal. of gasoline put through a tank in a year can be expected. A typical 10,000-gal. underground tank such as the one located at the Charlottesville residency having an annual throughput of approximately 100,000 gal. would have an annual loss of hydrocarbons of 100 lb., which is equivalent to the hydrocarbons in 17 gal. of gasoline. Although the standing loss for an underground tank appears to be negligible assuming a gasoline cost of \$1.00 per gallon, a pressure-vacuum vent costing \$70 would pay for itself in approximately 4 years.

The losses are greater for above ground storage such as the bulk storage at the Culpeper district. The standing loss for gasoline with a Reid vapor pressure of 10 psi is 89.5 lb. of hydrocarbons per 1,000 gal. of storage capacity. For a 40,000-gal. tank the annual storage losses for gasoline would be 597 gal. Assuming the vapor pressure of gasohol is 1 psi higher, the comparable loss for gasohol would be 657 gal. per year, or 10% greater. A \$70 pressure-vacuum vent would pay for itself in less than 2 months, assuming a gasoline cost of \$1.00 per gallon.

According to Erle Potter, equipment superintendent for the Culpeper district, the Virginia Department of Highways and Transportation has implemented the use of vapor recovery equipment in one county in Northern Virginia to satisfy air pollution requirements. This equipment consists of pressure-vacuum vents and the necessary hoses to return the vapors from the underground storage tank to the tank truck as the tank is filled. The equipment reduces fill losses as well as storage losses. Now that gasoline costs are exceeding \$1.00 a gallon, it is believed that the Department would be justified in using vapor recovery equipment on a statewide basis, or at a minimum purchasing pressure-vacuum vents for all storage tanks, because of the gasoline that would be saved. The savings, of course, would be greater if the Department uses gasohol.

Fuel Distribution and Dispensing Equipment

According to Fodge⁽³⁵⁾ preliminary indications are that gasohol has no effect on gaskets, seals, packing, etc., of new equipment and equipment previously used to handle leaded gasoline. However, he notes that leaks may occur in equipment previously used to handle no-lead gasoline when a changeover is made from no-lead gasoline to gasohol. He believes the gasohol has a shrinking effect on Buna-N and other compounds which have been swollen by no-lead gasoline. The ASPOE has made a similar statement concerning the use of gasohol in equipment previously used to handle no-lead gasoline.⁽³⁶⁾

It claims the alcohol in the gasohol causes the Buna-N to shrink and harden and, consequently, it recommends that all Buna-N seals be replaced with a fluroelastomer type compound seal (proprietary trade name Viton). Critical pieces of equipment include loader swing joints, hose swivels, and hose couplings.

No leaks were reported in the new 6,500 gal. capacity tank truck but an older 1,200 gal. capacity truck developed a leak after being used on one occasion to deliver and dispense a small amount of 200-proof alcohol. Similarly, the commercial tank truck used to deliver the alcohol to Culpeper was leaking when the alcohol was being pumped into the storage tank. A special pipe-sealing compound was used to prepare the piping required for the alcohol storage tank in Culpeper and a meter especially designed to dispense alcohol was installed. Consequently, no problems were encountered in handling the 200-proof alcohol used to prepare the gasohol. No leaks were reported from the handling of gasohol during the 8 months of the fleet test but this should not be taken to mean that leaks will not develop after a longer period of gasohol use. Obviously, alcohol-compatible materials and equipment will be required to handle alcohol, whereas it is reasonable to expect that most materials specifically designed to handle gasoline would handle gasohol adequately, at least in the short-term, since the gasohol contains only 10% alcohol.

Other observations during the 8 months of use of gasohol are as follows:

1. The filter on the pump at Boyds Tavern was changed at least four times following the changeover from gasoline to gasohol, whereas the filters were not changed more than once at the Charlottesville residency and at Yancey Mills.
2. Visits to the Boyds Tavern area headquarters on five afternoons in August and early September revealed that the pump would not work. Apparently, it would vapor lock on most of the warm afternoons in August and September. The fueling area has an above ground pump sitting in direct sunlight and, according to the timekeeper, Townsend, it has developed vapor lock with gasoline.
3. The metering device at the Yancey Mills area headquarters locked up in March after 8 months of use of gasohol and had to be replaced. However, the timekeeper there, K. Roach, indicated that the 10-year-old meter had a mechanical problem not associated with the use of gasohol.

4. According to the driver of the tank truck used to deliver the gasohol, a white, powder-like film formed on the metal alloy hose couplings following each delivery of gasohol. Lyon suggested that the powder was sulfuric acid formed by the water in the gasohol reacting with the sulfur in the gasoline.* A similar white powder had been noted at the Research Council several years earlier when pieces of metal fuel tank and fuel line were partially suspended in a 10% blend of methanol and gasoline for several months. It is not known if the white powder is indicative of any problems over the long term.

Safety Considerations

In most respects, the safety considerations applicable to gasoline are equally applicable to gasohol. However, the following items are worthy of mention.

1. Gasohol that comes in contact with human skin would be expected to remove more skin oil than would be removed by gasoline, because gasohol is a more powerful solvent.
2. Since gasohol has a higher vapor pressure than gasoline, persons handling and dispensing the fuel would be subjected to slightly higher concentrations of vapors.
3. Alcohol can enter the body in three ways: by ingestion, through the skin, and by the inhalation of the vapors. Persons taking drugs that react with alcohol should take particular care to avoid contact with gasohol.
4. The chances for the accidental ignition of gasohol are greater than for gasoline, because of the wider flammability limits of gasohol.
5. Although gasohol will burn at a wider range of fuel concentrations than gasoline, a recent field demonstration revealed that standard fire-fighting foams will extinguish a gasohol fire.⁽³⁷⁾ It is believed that the water in a conventional foam

* Personal communication, Harry B. Lyon, August 1980.

combines with the alcohol in the gasohol and causes it to separate, and the resultant foam can effectively act on the gasoline portion of the gasohol.

There are somewhat different concerns when handling alcohol, which include the following:

1. Alcohol would be expected to remove more skin oils than gasoline or gasohol.
2. Because alcohol has a Reid vapor pressure 1/5 to 1/10 that of gasoline, persons handling and dispensing it would be subjected to lower concentrations of vapors than for gasoline or gasohol.
3. Persons taking alcohol-reactive drugs and subjected to equal concentrations of liquid or vapor would be expected to experience a greater reaction from alcohol than from gasoline or gasohol.
4. The chance for accidental ignition of alcohol is, under most circumstances, much less than for gasohol or gasoline, because the flash point is much higher. However, it must be remembered that alcohol burns at a wider range of fuel concentrations than does gasoline.
5. Special, expensive foams are required to extinguish an alcohol fire because the flammability limits of alcohol are greater than can be handled by conventional foams. Acceptable foams include Aero Water PSC manufactured by National Foam and Light Water manufactured by the 3M Company. (38)

It appears that persons familiar with the handling and storage of gasoline and having a reasonable knowledge of gasohol can handle and store gasohol without encountering major problems. Somewhat more attention must be directed to the handling and storage of alcohol because of the requirement for special equipment. Recommendations made by the manufacturers of pumps, metering devices, and other fuel handling equipment concerning the use of fuel containing alcohol should be carefully considered. It will be necessary to keep abreast of technical developments relating to gasohol and alcohol because there is little, if any, available information on the handling and storage of gasohol and alcohol over long periods of time, and because many manufacturers are modifying their equipment to accommodate alcoholic fuels and warranties are being changed to cover their use.

Vehicle Performance

The performance of vehicles operating on gasohol as compared to no-lead gasoline is one aspect of gasohol use over which there is considerable controversy. This controversy is appropriate because if fuel consumption decreases with the use of gasohol, the alcohol effectively replaces more than 10% of the gasoline; and if fuel consumption increases, the opposite, of course, is true. Although fuel efficiency is the one aspect of vehicle performance that most people think of because of the high cost of fuel, other indicators of performance include driveability, exhaust emissions, oil consumption, maintenance requirements, and service life. For the fleet test conducted by the Department, fuel efficiency was determined from monthly fuel consumption records and from dynamometer tests, driveability was measured by surveying the drivers, exhaust emissions were determined using an infrared exhaust gas analyzer, and oil consumption and maintenance requirements were based on monthly records maintained by the drivers. Because in the test gasohol was used for a period of only 8 months, no significant change in service life could be attributed to its use.

As was reported earlier, monthly fuel and oil consumption and maintenance records were maintained by the principal drivers of 95 vehicles. Forty-five of the vehicles were operated on gasohol for 8 months and no-lead gasoline for 4 months. Fifty of the vehicles were operated on no-lead gasoline for all 12 months. The vehicles were paired based on vehicle type and similarities in their performance during the 4 months they all were operated on gasoline. Thirty-three satisfactory pairings were made. Descriptions of the 33 pairs are given in Table 2. To make the data more meaningful, the 33 pairs were put into subgroups depending on whether they were 3-ton dump trucks or lightweight vehicles and whether they were manufactured before or after 1976. All the vehicles had V-8 engines with 8.0/1 to 8.6/1 compression ratios. The lightweight vehicles had 2-barrel carburetors and the 3-ton dump trucks 4-barrel carburetors. Most of the lightweight vehicles had 318-in.³ engines, and the displacement of the engines in the 3-ton dump trucks varied from 360 to 392 in.³.

Driver's Comments

The principal driver of each of the vehicles operated on gasohol was requested at the end of the fleet test to complete a questionnaire on the performance of gasohol relative to gasoline. The voluntary questionnaire was completed for 37 of the 45 vehicles operated on gasohol as a part of the fleet test. Three drivers elected not to complete the questionnaire and questionnaires were not completed for five of the vehicles retired prior to completion of the test. The results of the questionnaire are shown in Table

Table 2. Description of Test Vehicles

Vehicle Group	No. of Pairs	Description	Average Odometer Reading, 1,000 mi.	Average Miles Driven Per Month
1977-80 Lightweight	4	1979-80 Dodge 1/2-ton Pickup	13	1,532
	6	1978 Dodge 1/2-ton Pickup	41	1,498
	1	1978 Plymouth 4-Dr. Sedan	37	1,729
	2	1977 Dodge 1/2-ton Pickup	85	2,397
1971-75 Lightweight	1	1975 American Motors Hornet	66	1,020
	2	1974 Dodge 3/4-ton Van	91	1,283
	2	1973-74 Dodge 1/2-ton Pickup	94	1,205
1977-80 3-ton Dump Trucks	1	1980 Ford	12	2,255
	4	1978 International	26	1,889
	3	1977 General Motors Corp.	49	1,816
1971-75 3-ton Dump Trucks	5	1974 Dodge	79	1,454
	2	1971-73 International	113	1,405

Table 3. Driver Responses to Questionnaire on Performance of Test Vehicles

Questionnaire Response	VEHICLE TYPE AND NUMBER				
	All Vehicles, 37	Lightweight Vehicles, 22	3-ton Dump Trucks, 15	New Vehicles 1977-1980, 26	Old Vehicles 1971-1975, 11
Starting					
Easier	9	5	4	7	2
Harder	6	2	4	4	2
No Change	22	15	7	15	7
Idling					
Smoother	10	5	5	9	1
Rougher	4	1	3	2	2
No Change	23	16	7	15	8
Power (Acceleration)					
Improved	16	12	4	13	3
Decreased	6	1	5	3	3
No Change	14	9	5	10	4
Engine Ping					
Decreased	22	18	4	15	7
Increased	3	0	3	2	1
No Change	12	4	8	9	3
Hesitation					
Decreased	6	5	1	6	0
Increased	10	2	8	7	3
No Change	21	15	6	13	8
Stalling					
Decreased	4	3	1	4	0
Increased	5	0	5	3	2
No Change	28	19	9	19	9
Fuel Consumption					
Less	5	2	3	5	0
More	5	3	2	4	1
No Change	25	16	9	15	10
VDHT Purchase					
10¢ more	4	1	3	4	0
5¢ more	4	4	0	1	3
Same	13	10	3	11	2
5¢ less	2	2	0	2	0
10¢ less	8	3	5	5	3
Other	1	0	1	0	1
Personal Purchase					
10¢ more	6	2	4	6	0
5¢ more	1	1	0	1	0
Same	13	12	1	7	6
5¢ less	3	2	1	3	0
10¢ less	5	3	2	4	1
Other	6	1	5	4	2

With the exception of engine ping, which a majority of the drivers reported to be less with gasohol, no difference between gasohol and gasoline was reported for the 37 vehicles. It is of interest that the reduced engine ping was not noted by many drivers of the 3-ton dump trucks; the majority reported no change. Also, for the lightweight vehicles, the majority felt that power was improved with gasohol. On the other hand, the majority of the operators of the 3-ton dump trucks reported an increase in hesitation with gasohol. To provide an indication of their overall opinion of gasohol, the drivers were asked at what price relative to that of no-lead gasoline the Department should purchase gasohol. Most said at the same price, but 5 of the drivers of the 3-ton dump trucks felt gasohol should be purchased at a cost of 10¢ less per gallon. When asked the same question concerning the purchase of gasohol for use in their personal vehicles, most cited the same price; however, 5 of the drivers of the 3-ton dump trucks selected "other" and indicated they would not purchase gasohol at any price. As can be seen from the questionnaire results, there was a wide variety of feelings concerning the performance of gasohol versus that of gasoline, but the majority found gasohol to be an equivalent and acceptable substitute for no-lead gasoline.

Fuel Consumption

Monthly Records

The results of comparisons of fuels consumed based on a linear regression analysis of the data collected over a 12-month period for 33 pairs of vehicles are shown in Table 4. As shown in this table, the mileage was better with no-lead gasoline for all groups, with the exception of the 1977-80 model 3-ton dump trucks, for which miles per gallon was 1.63% better for gasohol. A statistically significant difference at the 0.05 significance level based on the Wilcoxon signed ranks test⁽³⁹⁾ was found for both the 1977-80 model lightweight vehicles and for all model lightweight vehicles. A statistically significant difference at the 0.10 significance level was found for the 1971-75 model vehicles of both types and for all model vehicles. No significant difference in miles per gallon could be found for the 3-ton dump trucks, probably because the number of vehicles in the group was small and the performance was variable. In general, the newer model vehicles performed much better on gasohol than did the vehicles manufactured before 1976. Possible explanations for this include marginally higher octane requirements for newer vehicles⁽⁴⁰⁾ and greater storage losses for older vehicles.

Table 4. Differences in Fuel Consumption Based
on Linear Regression Analysis

Vehicle Description	No. of Pairs	Percent Change in Miles Per Gallon for Gasohol Relative to Gasoline
1977-80 Lightweight Vehicles	13	- 2.73**
1977-80 3-ton Dump Trucks	8	+ 1.63
1977-80 Both Types	21	- 1.26
1971-75 Both Types	12	- 8.41*
1971-80 Lightweight Vehicles	18	- 3.70**
1971-80 3-ton Dump Trucks	15	- 4.99
1971-80 Both Types	33	- 3.91*

Significant difference between gasohol and gasoline based on Wilcoxon signed ranks test at:

- * 0.10 significance level
- ** 0.05 significance level

A plot of the fuel consumption data for the 18 pairs of lightweight vehicles is shown in Figure 4. The data points represent the ratio of fuel consumed by the gasohol vehicle to the fuel consumed by the gasoline vehicle (y axis) plotted as a function of the ratio of the miles traveled by the gasohol vehicle to the miles traveled by the gasoline vehicle (x axis) for each pair. The solid line is the curve of the best fit for the data and the dashed line represents equal rates of fuel consumption. The point of interest is where x equals 1 (both vehicles travel the same distance) for which $y = 1.0384$, indicating that the gasohol vehicles consumed 3.84% more fuel than the gasoline vehicles to travel the same distance. This figure corresponds to a 3.70% smaller miles per gallon value for the gasohol vehicles relative to the gasoline vehicles. A linear regression of the data taken during the control period showed no significant difference in performance between the gasohol vehicles and the gasoline vehicles when both were operated on gasoline.

To identify possible seasonal or long-term use effects on the performance of gasohol relative to gasoline, the fuel consumption data were used to determine the average bimonthly miles per gallon for the various groups of vehicles. A bimonthly comparison of miles per gallon for the 21 pairs of 1977-80 model vehicles of both types can be seen in Figure 5. During the months of June through July 1979 and April through May 1980 both groups of vehicles were operated on gasoline. The other data represent comparative miles per gallon for operation on gasohol and gasoline. It can be seen that, in general, the difference in miles per gallon between gasohol and gasoline remained relatively constant throughout the test period. In fact, the relationship between the two closely approximated the theoretical relationship shown in Figure 5 that would be expected based on the heating values of the two fuels, which is 3.4% less for gasohol. With the exception of the data for the 3-ton dump trucks, which were too erratic to allow conclusions, trends similar to those shown in Figure 5 were found for the other groupings of vehicles.

It was anticipated that the monthly records maintained by the principal drivers of the vehicles would provide an indication of an improvement or deterioration in vehicle performance that might be attributed to the use of gasohol. Although the fleet test covered only an 8-month period of gasohol use, there was no apparent improvement or deterioration in performance. Furthermore, a linear regression analysis on the fuel consumption data for the gasohol vehicles operating on gasoline after having used gasohol for 8 months as compared to operation on gasoline before using gasohol showed no significant difference in performance between the two periods. A similar result was found for the gasoline vehicles. Although a longer period of operation on gasohol would not likely cause a progressive improvement in

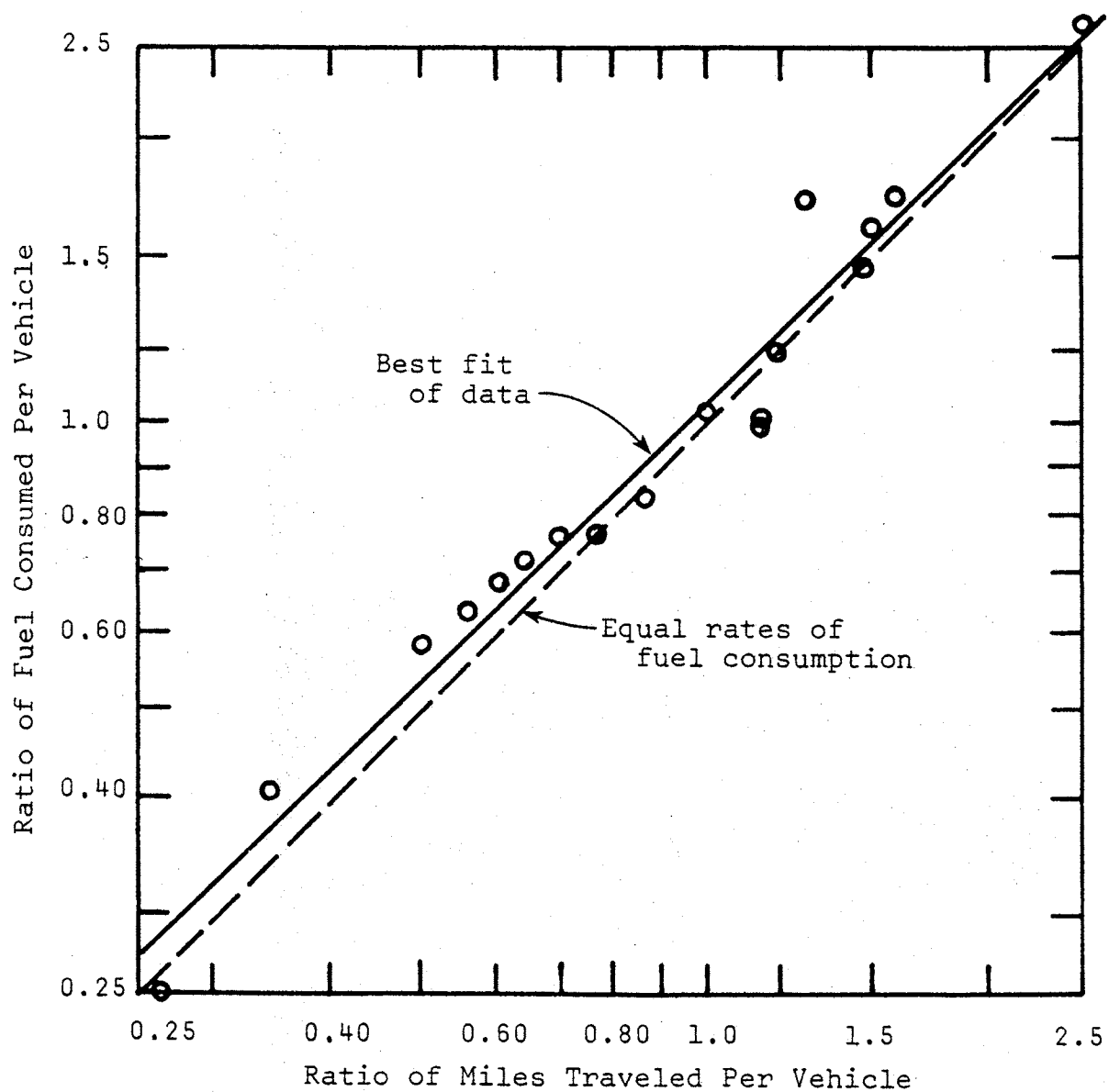


Figure 4. Fuel consumption for gasohol relative to gasoline, 18 pairs of lightweight vehicles.

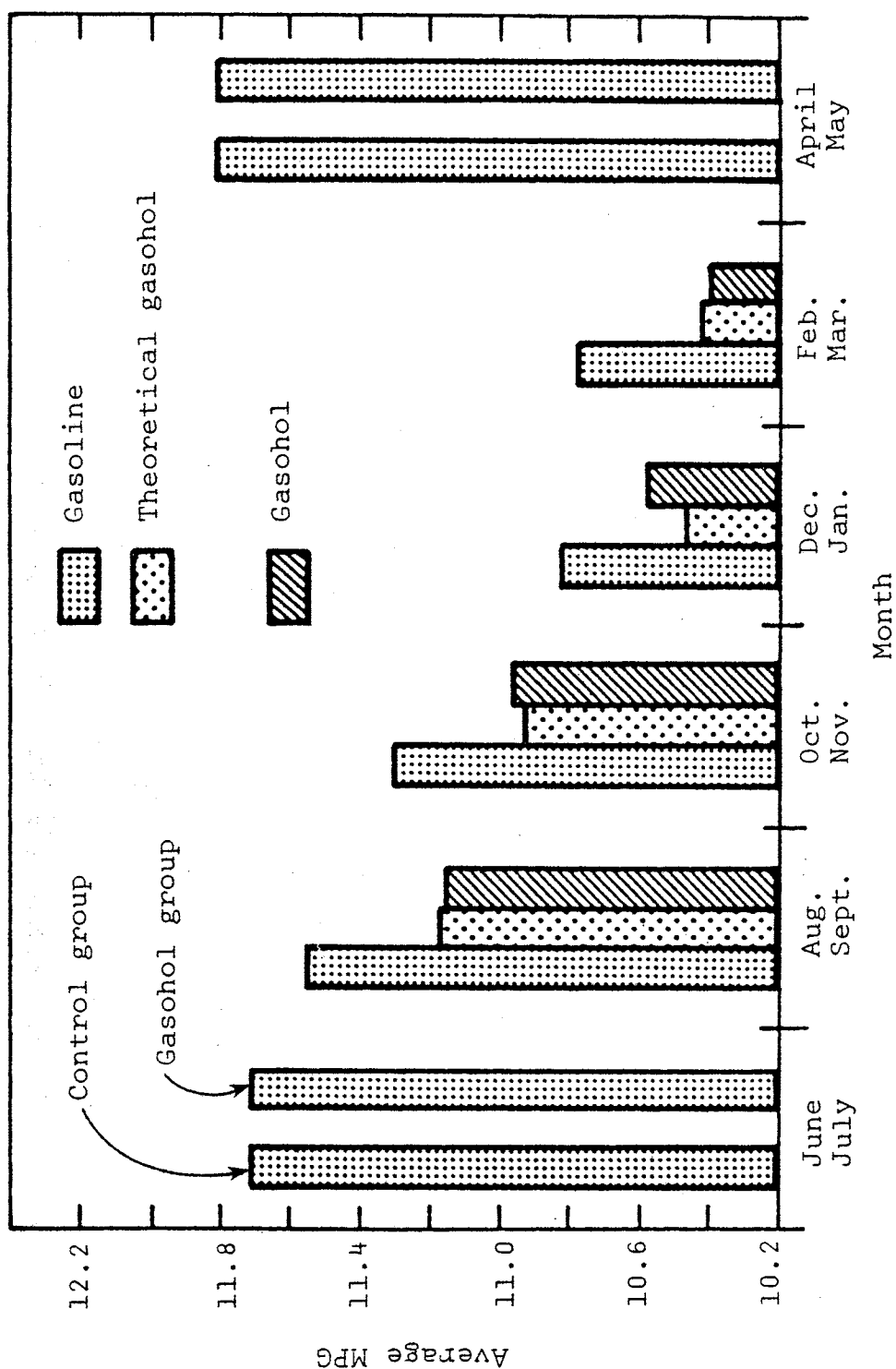


Figure 5. Seasonal fuel consumption.

performance, a longer period would likely be required to show any significant deterioration in performance.

Dynamometer Tests

Since some people consider fuel consumption records maintained for everyday operations to be unreliable because of the many factors that can affect mileage, additional data for the 1977-80 model lightweight vehicles were obtained by placing 8 vehicles on a dynamometer and measuring fuel consumption for different controlled operating conditions.

The basic procedure involved (1) placing a vehicle on a dynamometer, (2) disconnecting the fuel line between the carburetor and fuel pump, (3) connecting a fuel line to the carburetor from a fuel pump which could supply fuel from external containers, (4) operating the vehicle on the dynamometer until the temperature gage on the dashboard indicated the vehicle had reached normal operating temperature, and (5) operating the vehicle for a prescribed period of time at prescribed speeds and loads on preweighed 1-liter containers of fuel.

The vehicles were subjected to three loading conditions: an idle condition comparable to operating at a stop light, a light load condition comparable to operating on a level road, and a heavy load condition comparable to climbing a 3% to 4% grade. All the vehicles were operated at 25, 40, and 55 mph for the light load condition and most were operated at 25, 40, and 47 mph for the heavy load condition. The 47 mph was selected as the upper limit for the heavy load condition because above this speed the automatic transmissions of the 1978 model vehicles begin to shift down into second gear. Also, the heavy load condition had to be adjusted slightly for the 1979 and 1980 model vehicles because of their lower horsepower. A threaded rod was connected to the accelerator linkage on the carburetor so that a constant speed could be maintained and a stop watch was used to time the operation at each speed. The usual procedure was to operate the vehicle under heavy load at 25, 40, and 47 mph on either gasoline or the test fuel; then switch fuels and repeat the speed sequence; adjust the dynamometer to a light load condition and operate the vehicle at 25, 40, and 55 mph, switch fuels and repeat the sequence; and complete the test by operating the vehicle on each fuel while in gear but with the emergency brake applied. The test was designed to subject the vehicle to the variety of driving conditions encountered in everyday driving while eliminating the effects of driving habits, weather, and other factors.

The average results obtained for five 1978 Dodge 1/2-ton pickup trucks are shown in Figure 6. It's interesting to note that under light load the miles per gallon obtained on gasohol at the various speeds approximated the values that would be expected based on the heating value of gasohol. However, under heavy load and at higher speeds, conditions under which engine ping was readily detectable, the higher octane and improved combustion characteristics of the gasohol relative to gasoline offset some or all of the loss in mileage due to the lower heating value. The general trends seen in Figure 6 were demonstrated by most of the vehicles tested on the dynamometer. Exceptions were that 2 of the 5 vehicles exhibited very low mileage on gasohol at 25 mph and under heavy load, which explains why the data point for this operating condition is lower than would be expected based on performance under other operating conditions.

The results of all the dynamometer tests are shown in Table 5. Under the heading "average fuel consumption", the average miles per gallon (mpg) for six speeds and loading conditions and the hours per gallon (hpg) at idle, for both gasoline and gasohol are reported for each of the 8 vehicles. It should be obvious from the results for the five 1978 Dodge pickup trucks that because of differences in the conditions of the engines, the tolerances to which the vehicles are manufactured, the way the carburetors are adjusted, and factors related to duplicating test conditions from one day to the next different fuel consumption values can be obtained for similar vehicles. Therefore, it is believed that a better comparison of the performance on gasohol versus the performance on gasoline can be had by using a ratio for each vehicle as shown on the right side of Table 5. Also, by using a ratio and the formula $(6A + B)/7$ the idle operating condition could be combined with the other six operating conditions.

Table 5 shows that only 2 of the 8 vehicles tested achieved more miles per gallon on gasohol than on gasoline for the six speeds and loads used in the test. However, 6 of the 8 vehicles tested idled for a longer period of time on gasohol. Combining the idle condition with the other six conditions reveals that 5 vehicles performed better on gasoline, 2 vehicles better on gasohol, and 1 the same on both fuels. A statistically significant difference between gasohol and gasoline at the 0.025 significance level was found using the data obtained for the 1978 Dodge pickup trucks and the 7 Chrysler vehicles for the six speeds and loads. The significance level dropped to 0.05 when the idle condition was included. Gasohol performed better at the idle condition as shown by the statistically significant difference between gasohol and gasoline at the 0.10 significance level.

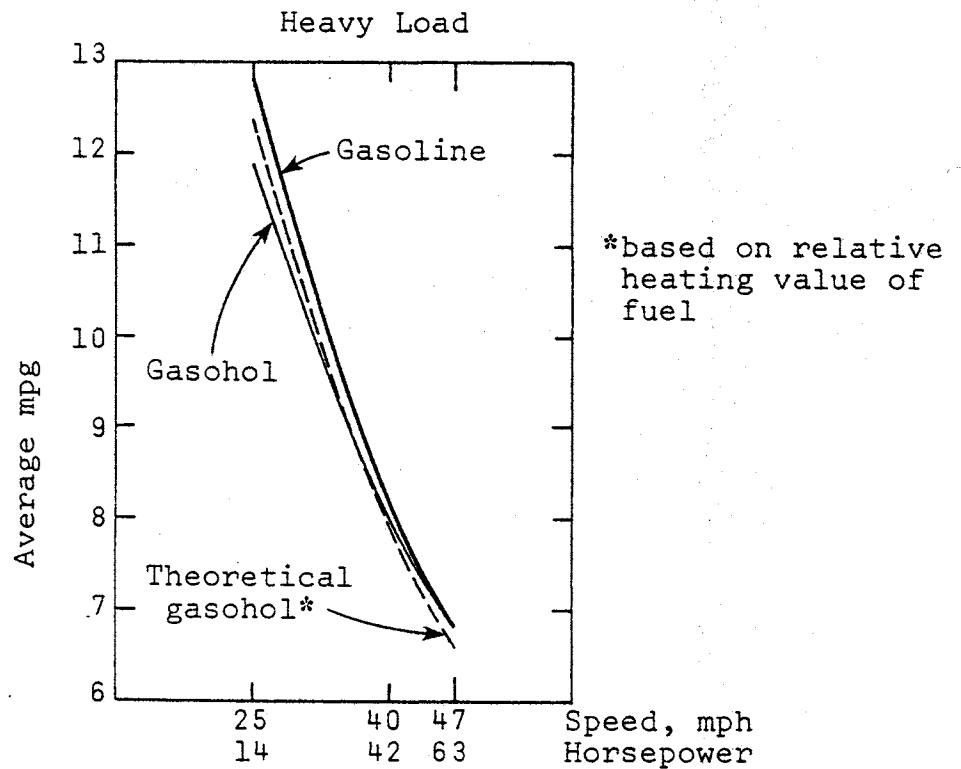
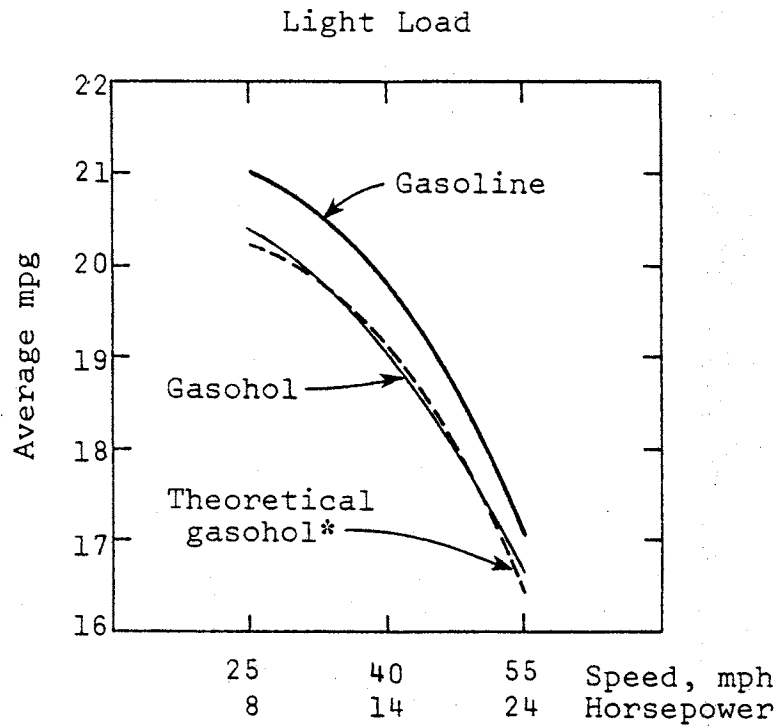


Figure 6. Results of dynamometer tests for fuel consumption, five 1978 Dodge $\frac{1}{2}$ -ton pickup trucks.

Table 5. Differences in Fuel Consumption Based on Dynamometer Tests

Vehicle		Loc.	Odometer Reading 1,000 miles	Average Fuel Consumption			Ratio Gasohol/Gasoline		
				Gasoline MPG	Idle HPG	Gasohol MPG	MPG (A)	Idle (B)	$\frac{6A+B}{7}$
36566	78 Dodge Pickup	R.C.	23	14.4	1.65	13.8	0.953	0.910	0.946
36643	78 Dodge Pickup	C.R.	23	14.7	1.55	14.3	0.974	1.068	0.987
36775	78 Dodge Pickup	C.D.	20	14.5	1.70	14.5	0.998	1.014	1.000
36443	78 Dodge Pickup	C.D.	48	14.0	1.45	13.0	0.923	1.024	0.937
36648	78 Dodge Pickup	C.R.	39	13.7	1.52	13.5	0.985	1.022	0.991
40766	80 Dodge Pickup	C.D.	9	18.7	1.44	18.0	0.963	1.009	0.970
P-8383	78 Plymouth 4-Dr.	C.D.	38	15.9	1.13	16.1	1.014	0.998	1.011
P-9001	79 Chev. S. W.	R.C.	19	16.1 ^a	2.01	16.7	1.039	1.056	1.041
Avg., 5	78 Dodge Pickups		31	14.3	1.57	13.8	0.966***	1.006	0.972**
1 Avg., 7	Chrysler Vehicles		29	15.1	1.49	14.7	0.974***	1.005	0.977**
3 Avg.	All 8 Vehicles		27	15.3	1.56	15.0	0.981*	1.012*	0.985
36648	78 Dodge Pickup	C.R.	39	13.7	1.52	13.5 ^b	0.985 ^b	1.022	0.991
36648	78 Dodge Pickup	C.R.	39			13.1 ^b	0.955 ^b	--	--
36648	78 Dodge Pickup	C.R.	39			12.9 ^c	0.940 ^c	--	--
P-9001	79 Chev. S. W.	R.C.	19	16.1 ^a	2.01	16.7	1.039	1.056 ^b	1.041 ^b
P-9001	79 Chev. S. W.	R.C.	19			16.4 ^b	1.020 ^b	1.062 ^b	1.026 ^c
P-9001	79 Chev. S. W.	R.C.	19			15.1 ^c	0.938 ^c	1.104 ^c	0.962 ^c

^a Vehicle may not have reached normal operating temperature prior to beginning the gasoline tests.

^b 20% ethanol

^c 30% ethanol

Significant difference between gasohol and gasoline based on Wilcoxon signed ranks test at:

* 0.10 significance level

** 0.05 significance level

*** 0.025 significance level

Table 5 shows that for the 8 vehicles tested there was a 1.5% lower value for miles per gallon for gasohol as compared to that for gasoline. However, it is the writer's judgement that the 4.1% improvement in performance for gasohol reported for the 1979 Chevrolet station wagon resulted in part from the vehicle not being completely warmed up prior to initiating the gasoline tests. The vehicle was not equipped with a temperature gage. If the 1979 Chevrolet station wagon is eliminated from the data, a 2.3% reduction in miles per gallon is indicated for the 7 Chrysler vehicles, which provide a representative sample of the 1977-80 model lightweight vehicles involved in the fleet test. This figure agrees with the 2.7% lower value in miles per gallon for these vehicles based on the monthly data reported by the vehicle drivers (see Table 4).

It is reasonable to expect that if the addition of 10% alcohol to gasoline has a negative effect on fuel consumption, the addition of 20% or 30% alcohol would have a similar but more pronounced effect. To observe the effect of higher concentrations of alcohol on fuel consumption, 2 of the vehicles which were placed on the dynamometer were also operated on blends of alcohol and gasoline containing 20% and 30% alcohol. The results are shown at the bottom of Table 5 and some of the data are shown in Figure 7. It can be seen from the results in Table 5 and Figure 7 that mileage tended to decrease as the alcohol content was increased, probably because of the lower heating value of alcohol relative to that of gasoline. However, a vehicle does not operate at peak efficiency on gasoline at every speed and loading condition, and for conditions where the vehicle is not operating efficiently on gasoline, it is believed that the higher octane and the cleaner burning characteristics of the alcohol tend to improve efficiency and thereby offset some or all of the losses associated with the lower heating value. It is particularly interesting to note that for the 1979 Chevrolet station wagon operating at the idle condition the hours of operation per gallon of fuel increased as the alcohol content was increased. This behavior deserves further evaluation. It must be remembered that the curves in Figure 7 were drawn based on tests of only 1 vehicle operating at each loading condition and, therefore, relative performances on the different fuels are not as well defined as in Figure 6 where the curves are based on the average of the results for 5 vehicles.

As has been mentioned, the purpose of the dynamometer tests was to measure fuel consumption under controlled operating conditions and at the same time to eliminate factors such as driving habits and weather that can affect fuel consumption. Table 6 shows the relationship between fuel consumption as determined by the dynamometer test and that from the daily records maintained for 6 vehicles. Although the effects of evaporative losses and warmup performance are not reflected in the dynamometer data, reasonably close agreement between the two sets of data suggests that the dynamometer test provides a realistic simulation of driving conditions. Furthermore, it is believed that since the dynamometer test can be carefully controlled it can provide a much better and more easily determined indication of relative fuel consumption for operation on different fuels and should be used for any future evaluations of fuel consumption that may be desired.

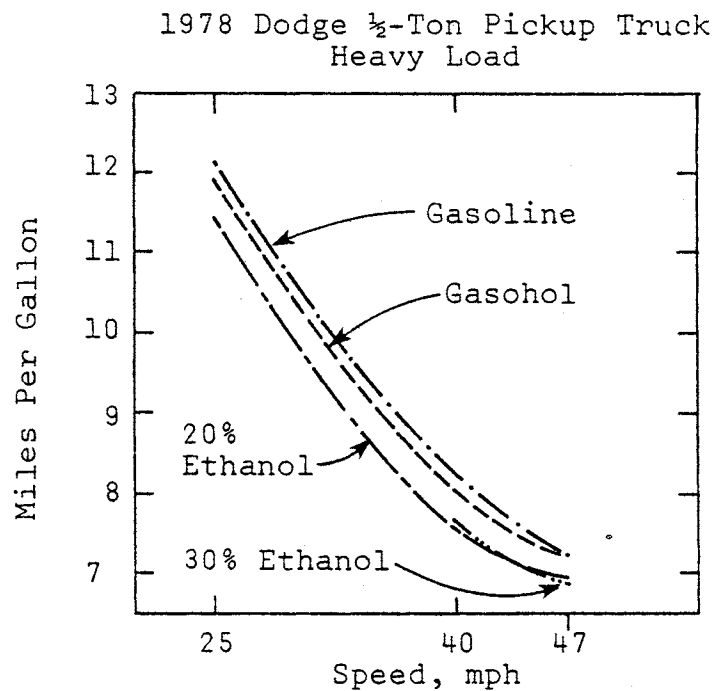
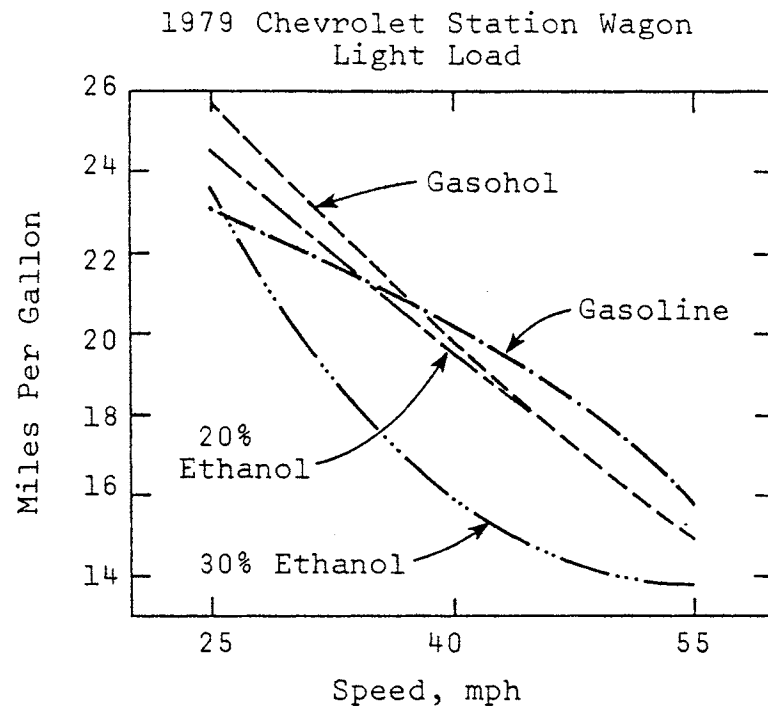


Figure 7. Dynamometer data on fuel consumption as a function of alcohol content of fuel.

Table 6. Comparison of Dynamometer and Field
Data on Fuel Consumption

<u>No.</u>	<u>Vehicle</u> <u>Type</u>	<u>Fuel Consumption, mpg</u>	
		<u>Dynamometer</u>	<u>Field Data</u>
36643	1978 Dodge Pickup	14.7	14.9
36643	1978 Dodge Pickup ^a	14.3	14.0
36775	1978 Dodge Pickup	14.5	15.2
36443	1978 Dodge Pickup	14.0	16.1
36648	1978 Dodge Pickup	13.7	15.8
36648	1978 Dodge Pickup ^a	13.5	14.1
40766	1980 Dodge Pickup	18.7	17.0
P-8383	1978 Plymouth 4-Dr.	<u>15.9</u>	<u>16.0</u>
	Average	14.9	15.4

^a

Gasohol rather than gasoline.

General

Since gasohol differs from gasoline, one would expect differences to show up in the fuel consumption comparisons. Gasohol has a lower heating value and it is reasonable to expect that a vehicle carbureted properly and operating efficiently on gasoline of adequate octane would get fewer miles per gallon when operated on gasohol because of the 3.4% lower heating value of gasohol. The dynamometer tests and the field data indicate that, for the most part, this was the case for the vehicles in the fleet test. The dynamometer tests indicate a 1.5% to 3.0% reduction in mileage and the daily records maintained by the drivers indicate, for the most part, a 1.0% to 4.0% reduction. Probably because of overly rich carburetion or inefficient combustion, and because of occasional instances of excessive pinging because of low octane, some vehicles showed a better fuel economy on gasohol than would be expected based on its heating value.

The Office of Technology Assessment of the U. S. Congress has reported miles per gallon to be 0 to 4% less for gasohol than for no-lead gasoline.⁽⁴¹⁾ The EPA has reported 1% to 5% less for gasohol.⁽⁴²⁾ General Motors has reported that fuel economy may vary with older vehicles, but vehicles manufactured in 1980 have closed-loop fuel control systems that will likely ensure a 3% reduction in miles per gallon for gasohol.⁽⁴³⁾ On the other hand, Scheller reports that miles per gallon increases 7% with gasohol.⁽⁴⁴⁾ A wide variety of results of tests for fuel economy can be found in the literature, probably because of the multitude of differences between vehicles, the variety of operating conditions vehicles are subjected to in everyday operations, the difficulties inherent in accurately measuring fuel economy, the tremendous amount of publicity given gasohol since the OPEC oil embargo, the financial interests of many promoters in the production of alcohol or alternative liquid fuels, and a host of other reasons. From a technical standpoint, as long as the Department can purchase no-lead gasoline having an acceptable octane number, it is reasonable to expect that the use of gasohol would cause a 2% to 3% reduction in miles per gallon that would, in turn, require a comparable increase in fuel purchases, although gasoline consumption would be reduced by 7% to 8%.

Exhaust Emissions

In the literature there are numerous claims that major improvements in air quality can be achieved by substituting gasohol for gasoline. For example, recent tests conducted on eleven 1978 and 1979 model vehicles by the EPA showed a 33% reduction in carbon monoxide, an 8.4% reduction in hydrocarbons, and a 6.4% increase in nitrogen oxide emissions.⁽⁴⁵⁾ According to General Motors, the use of gasohol in older model vehicles would likely reduce carbon monoxide emissions but may cause either an increase or decrease in nitrogen oxide emissions, whereas its use in vehicles manufactured in 1980 and later will likely have little effect on emissions.⁽⁴⁶⁾

To obtain information for comparison with that reported in the literature, the exhaust emissions from ten 1/2-ton pickup trucks and ten 3-ton dump trucks were analyzed using a Pulsar infrared exhaust gas analyzer provided by the Piedmont Virginia Community College. The analyzer is designed to measure carbon monoxide in percent and hydrocarbons in parts per million (ppm) of a sample of exhaust gas taken from a vehicle operating at idle and at normal operating temperature. The equipment cannot be used for measurements of cold-start or evaporative emissions, which must be made with the more sophisticated equipment and procedures required by the federal test procedures.⁽⁴⁷⁾

The results obtained for the 20 vehicles tested using the infrared analyzer are shown in Table 7. The vehicles were operated at 3 speeds for each of 2 loading conditions and at idle. The results for the vehicles operating at idle agree qualitatively with those reported by most other testing organizations, since as a group the vehicles operating on gasohol emitted statistically significant less carbon monoxide and nonsignificant less hydrocarbons at the 0.10 significance level. The gasohol-powered vehicles also emitted statistically significant less hydrocarbons for the other 6 conditions under which the vehicles were tested. It is clear that for most vehicles a switch to gasohol will decrease carbon monoxide emissions but may increase or decrease hydrocarbon emissions depending upon the adjustment of the carburetor, the condition of the vehicle, and the operating condition.

If the state of Virginia should amend its periodic vehicle inspection program to require vehicles to pass an emissions test, it is likely that equipment similar to that used in this study would be put into use at inspection stations and that the sample would be taken at idle. In the case of vehicles manufactured in 1978 or earlier, operation on gasohol would improve the probability of their meeting carbon monoxide requirements.

However, the federal test procedure provides a better indication of the true effect of gasohol use on atmospheric pollution.⁽⁴⁸⁾ This procedure provides information on both cold-start and evaporative emissions. Because the vapor pressure of gasohol is higher than that of gasoline, the EPA has reported that evaporative emissions are significantly greater for gasohol.⁽⁴⁹⁾ For example, in the diurnal test, which provides an indication of the emissions produced by fuel being heated in the fuel tank, evaporative emissions were 61% higher for gasohol. For the hot soak test, which provides an indication of the emissions produced as fuel evaporates in the carburetor, evaporative emissions were 64% higher. General Motors has reported evaporative emissions to be about 30% greater for gasohol.⁽⁵⁰⁾ When the evaporative emissions are combined with the exhaust emissions for on-the-road operation, there tends to be a net increase in hydrocarbon emissions resulting from the use of gasohol. The EPA has reported the net increase to be 18%.⁽⁵¹⁾

It would seem that the use of gasohol can help improve air quality in certain situations where carbon monoxide is a major concern but smog induced by hydrocarbons is not a problem, for example; whereas in other situations, such as those characterized by a high concentration of parked vehicles and service stations, the use of gasohol could lead to a deterioration in air quality because of higher levels of evaporative emissions. The introduction of closed-loop fuel control systems on vehicles manufactured in 1980 and later will likely eliminate the reductions in carbon monoxide that can be attributed to gasohol; and the application

Table 7. Percent Changes in Emissions for Gasohol Relative to Gasoline

Vehicle Description	No. Pairs (P)	Carbon Monoxide		Hydrocarbons		
		6 Tests (A)	Idle (B)	6 Tests (A)	Idle (B)	6A+2B 8
1978 Dodge 1/2-ton Pickup	4	- 45.7	- 55.6	- 40.8	+ 17.1	- 30.7
1977 Dodge 1/2-ton Pickup	1	+489.5	- 97.7	- 71.6	- 67.8	- 70.0
All Dodge 1/2-ton Pickup	5	- 12.5	- 75.5	- 48.9**	- 15.2	- 41.4
1978 Dodge 3-ton Dump	3	- 43.0	- 50.6	+ 7.8	+ 18.3	+ 38.4
1977 GMC 3-ton Dump	1	+ 36.6	- 71.9	- 20.8	+100.0	+ 65.6
1974 Dodge 3-ton Dump	1	- 81.2	- 97.5	- 29.6	- 91.1	- 65.9
All 3-ton Dump	5	- 45.6	- 75.8***	- 6.9	- 21.7	+ 8.4
All Vehicles	10	- 31.0	- 75.6***	- 31.0**	- 18.9	- 20.3

(P) Vehicles paired according to type and odometer reading.

(A) Average of 6 operating conditions consisting of 2 loads and 3 speeds.

(B) Average of 2 tests.

Significant difference between gasohol and gasoline based on Wilcoxon signed ranks test at:

- * 0.10 significance level
- ** 0.05 significance level
- *** 0.025 significance level

of more effective evaporative emissions control equipment on newer model vehicles, the application of vapor control devices on handling and storage equipment, and adjustments to the volatility of the base gasoline from which gasohol is prepared will all help eliminate the detrimental effect of increased hydrocarbon pollution from gasohol. Therefore, the net effect of the increased use of gasohol on air quality in the future will likely be negligible.

Maintenance

Unscheduled Maintenance

During the fleet test reported here, the following unscheduled maintenance was performed on the fuel systems of the vehicles and equipment operated on gasohol.

1. The fuel pumps failed and were replaced on three (seven percent of test group) vehicles; a 1978 International 3-ton dump truck (19,767 miles), a 1975 AMC Hornet (57,621 miles), and a 1974 Dodge pickup truck (63,493 miles). No fuel pumps were replaced on the vehicles in the control group.
2. The carburetor was adjusted on a 1977 Dodge pickup truck because of hot-start problems (possibly vapor lock) encountered during warm weather.
3. The sending unit (which contains a filter) located in the fuel tank was replaced on a 1975 AMC Hornet and it was noted that the elastomeric o-ring which seals the unit in the tank had swelled to the point that it had to be replaced.

On the plus side for gasohol, Ken Roach, the timekeeper at the Yancey Mills area headquarters, reported that it is quite common to change the fuel filters on several vehicles during the winter months because of ice developing in the filter, but that during the winter that gasohol was used, no fuel filters froze.

Oil Consumption

The records on oil consumption showed no significant differences between the gasohol-powered vehicles and the gasoline-powered vehicles. This is demonstrated by the bimonthly oil consumption data shown in Figure 8.

Engine Wear

Samples of oil taken before and after use in three pairs of vehicles were sent to the Fuels and Lubricants Division of the U. S. Army at Fort Belvoir, Virginia, for the analyses of metals content.

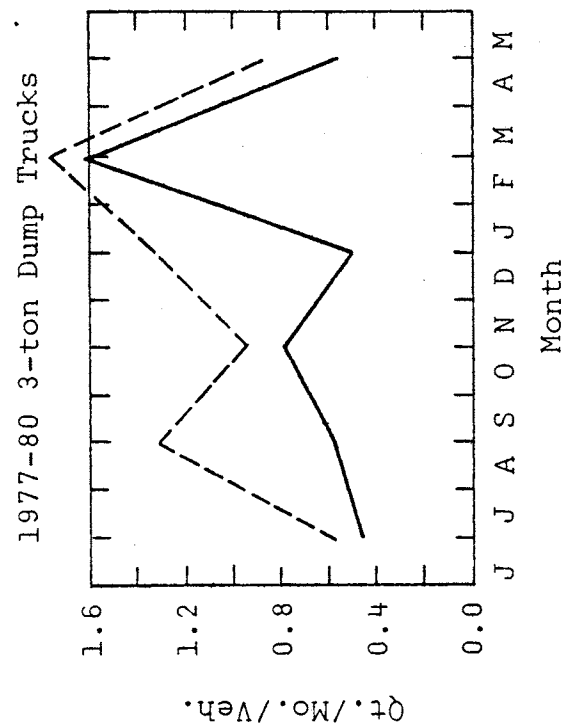
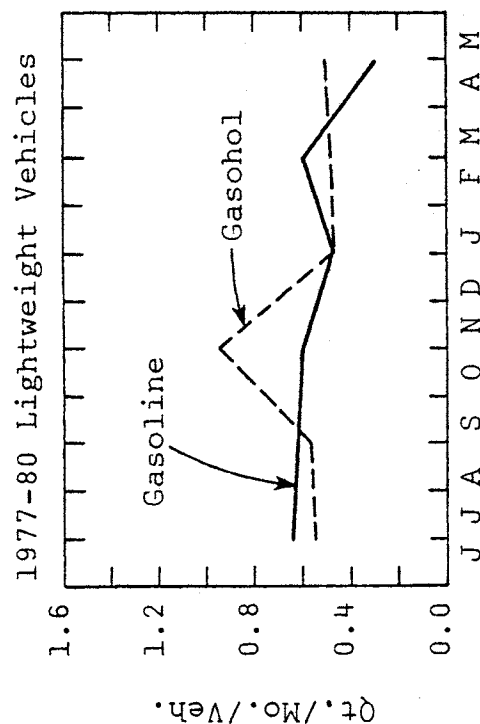
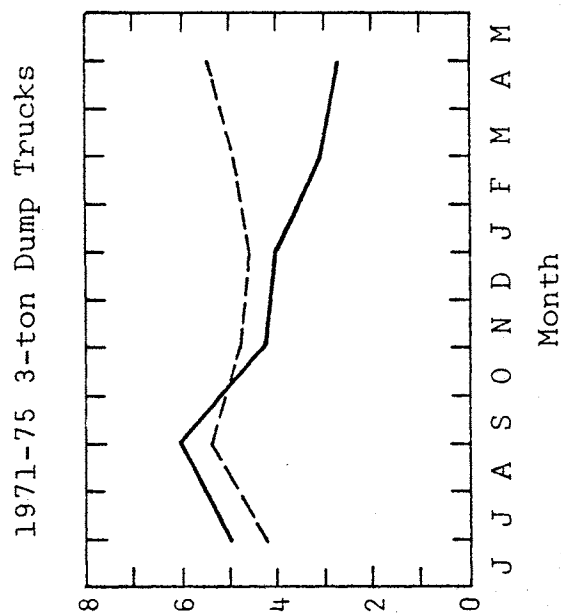
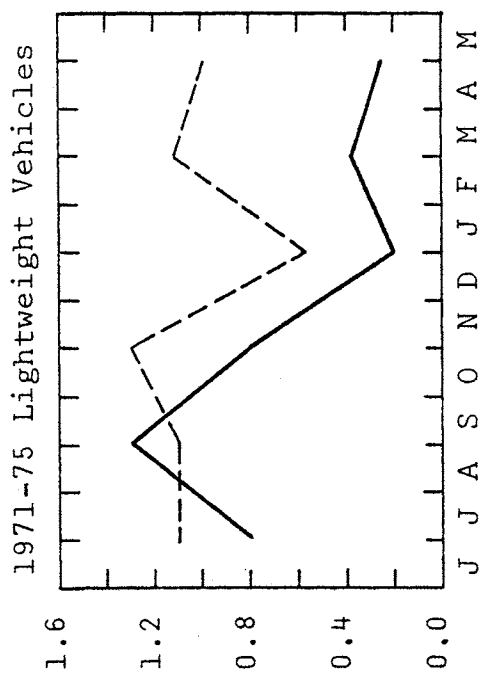


Figure 8. Average monthly oil consumption for groups of vehicles.

The iron, copper, and aluminum contents of the used oil indicate wear in a vehicle engine, and the total ppm of these metals per 1,000 miles of vehicle operation were greater for gasohol than for gasoline for the three pairs of vehicles (see Table 8).^{*} The conclusion to be drawn from Table 8 is that further consideration should be directed to engine wear for operation on gasohol.

Table 9 gives tentative results of 100-hour, single-cylinder engine laboratory tests under way at the Southwest Research Institute.⁽⁵²⁾ The increases in engine wear for the operation on the indicated alcohols and blends of alcohol and gasoline as compared to no-lead gasoline are based on the iron content of the oil. An increase in oil viscosity and oil dilution has been found for both neat methanol and neat ethanol as compared to no-lead gasoline, but no significant effect on lubrication has been found for blends of alcohol and gasoline. The tentative results clearly imply that the greatest rate of wear by far is occurring with neat methanol, and that neat ethanol is a distant second. The rate of increase in wear for the 15% methanol blend is only 9% that of neat methanol. Based on this information one would expect wear to be marginally greater (approximately 10%) for gasohol than for gasoline. For practical purposes, this increase might be of questionable significance.

Small Engines

Engineers at Tecumseh, a manufacturer of small engines, currently recommend that gasohol not be used as a fuel in small engines such as those used for lawn mowers and snow blowers because during the storage, particularly long-term, off-season storage, the alcohol reacts with the water in the fuel and forms a strong acid that can damage metal, rubber, and plastic fuel system and engine parts.⁽⁵³⁾ Damage could be avoided if the fuel system were drained prior to storing the equipment.

General

The potential for problems resulting from the incompatibility of fuels and the materials in the fuel system, and problems from increased engine wear for operation on gasohol and other blends of alcohol and gasoline, are being studied by the major automotive manufacturers and the U. S. Department of Energy.⁽⁵⁴⁾ The results of tests on the performance of vehicles operating on gasohol over long periods are not available, but most reports relating to short-term performance have indicated no major problems. It appears that the age of the vehicle is a major factor, and it is expected that the automotive manufacturers will modify vehicles manufactured in the future to eliminate any problems found in the current testing programs. The new car warranties issued by all of the major auto manufacturers cover the use of gasohol.

* Personal correspondence, Maurice E. LePera, Chief, Fuels and Lubricants Division, April 1980.

Table 8. Metals Content of Oil Samples,
ppm/1,000 miles

<u>Vehicle Pairs</u>	<u>Gasoline</u>	<u>Gasohol</u>
1978 Plymouth Sedans	5.0	6.6
1978 Dodge 1/2-ton Pickups	0.5	11.6
1978 International 3-ton Dump Trucks	13.2	16.2

Table 9. Tentative Results for Engine Wear

<u>Fuel</u>	<u>Percent Increase in Engine Wear</u>
Neat methanol	680
Neat ethanol	180
15% methanol	60
15% ethanol	(inconclusive)

Source: Reference 52.

According to Gordon Allardyce of the Chrysler Corporation, vehicles operating on gasohol are susceptible to filter plugging, possible problems with aluminum corrosion in carburetors, and potential long-term problems with elastomeric materials. Therefore, he opines that over the life of a vehicle it may be necessary to substitute some materials and make changes in hardware, but sees no insurmountable problems with durability. (55) Similarly, General Motors reports that fleet tests are being continued but can't predict at this time how each vehicle in the current population will respond to gasohol. They report that elastomers deteriorate more with gasohol than with gasoline, but they are optimistic that problems which arise from the incompatibility of materials can be solved. (56)

The fleet test and results reported by others support the conclusion that although fuel system parts may fail slightly more often, no major maintenance problems will be encountered from the short-term use of gasohol. It is not expected that major or insurmountable problems with maintenance or durability will be encountered with the long-term use of gasohol. However, it will be to the advantage of the Virginia Department of Highways and Transportation to keep abreast of technical developments as they are reported by others so as to be in a position to make cost-effective decisions concerning the operation of vehicles on gasohol.

Fuel Cost

The relative abundance and low price of petroleum have historically been the principal reasons that alcohol has not gained wide acceptance as a motor fuel in this country. In fact, prior to the oil embargo of 1973, the Virginia Department of Highways and Transportation was able to purchase all the gasoline it needed for 12¢ a gallon. However, its current cost is \$1.00 a gallon, which represents an 8-fold increase over the past 7 years. Although gasoline is readily available at present, the Department has had to deal with allocations in recent years. It's reasonable to expect that the cost of gasoline will continue to increase and shortages will continue to occur until liquid alternatives to petroleum become readily available.

The critical question to be considered in the use of gasohol is: At what point in time will the cost of gasohol be competitive with that of gasoline? Gasohol is being sold commercially at a competitive price because the 4¢ per gallon federal fuel tax is not applied to gasohol and because 24 states have removed anywhere from 1¢ a gallon to all of the state tax on gasohol. (57) These subsidies don't apply to tax exempt organizations such as the Department. Many people believe that unsubsidized gasohol and

gasoline will eventually become competitive, and that gasoline will continue to increase in price and the price of alcohol will stabilize or decrease with the greater supply expected to be available as more alcohol plants are put into operation. On the other hand, others argue that because of the large amount of energy that goes into its production, alcohol will always cost more than gasoline. In Brazil, regular gasoline, which contains at least 5% alcohol, sells for \$2.11 a gallon, while alcohol sells for the relatively low price of \$1.30 a gallon. (58)

As mentioned earlier, the average cost for alcohol used in the gasohol required for this fleet test was \$1.72 per gallon. The average cost for no-lead gasoline during the same period was \$0.82 per gallon. The cost per gallon of the gasohol used in the study was by proportion $[\frac{.1(1.72) + .9(.82)}{1}]$ \$0.91, which is \$0.09 more per gallon than the cost of gasoline. The 130,000 gal. of gasohol used during the test resulted in an increase in fuel costs of \$11,700 because of the \$0.09 per gallon higher cost, and an additional \$3,200 because of the lower heating value of the alcohol in the gasohol. Therefore, for the fleet test it cost the Department 14% (\$14,900) more to operate its vehicles on gasohol than it would have to operate them on no-lead gasoline.

The current price of alcohol is approximately \$1.90 per gallon as compared to about \$1.00 for gasoline, which means it would cost 11% to 12% more to operate on gasohol at present prices. The Department currently purchases approximately 15 million gallons of no-lead gasoline each year. At current prices and assuming a 2% to 3% increase in purchases for gasohol, it would cost approximately 1.7 to 1.8 million dollars more to operate vehicles statewide on gasohol. The cost would be greater if the distributor would charge to mix the alcohol and gasoline. The Department should keep abreast of these costs so as to be in a position to make cost-effective decisions concerning the use of gasohol.

DISCUSSION OF RESULTS

The addition of 200-proof ethanol to no-lead gasoline changes the characteristics of the gasoline. Gasohol, which contains 10% 200-proof ethanol by volume, takes on the following characteristics relative to those of the gasoline from which it is prepared:

1. Heating value lower by 3.4%
2. Octane number higher by 3 numbers for $(R + M)/2$
3. Stoichiometric air-fuel ratio lower by 3.9%
4. Distillation curve depressed
5. Reid vapor pressure increased approximately 0.8 psi
6. Higher flammability limit increased
7. Water tolerance increased to a point then decreased

These differences had a measurable influence on the handling and storage requirements for the fuels and on the performance of the test vehicles.

With respect to vehicle performance, the questionnaires filled in by the drivers of the vehicles indicated that with the exceptions of a reduction in ping and, in some cases, an improvement in power, the majority of the drivers could detect no difference between engine performance on gasohol and performance on gasoline. However, the fuel consumption records maintained by the drivers and the results of the dynamometer tests for fuel consumption showed a significant reduction in miles per gallon for gasohol relative to gasoline for most vehicles. The 3.4% lower heating value of gasohol is believed to be principally responsible for the 1% to 4% reduction in mileage reported for most vehicles.

According to the manufacturers of the vehicles involved in the fleet test and the octane number reported for the no-lead gasoline, the octane of the gasoline was adequate for most of the operating conditions encountered by most of the vehicles. Therefore, it is believed that little improvement in mileage resulted from the higher octane of the gasohol. The newer vehicles may have benefited slightly more than the vehicles manufactured before 1976.

The stoichiometric air-fuel ratio is less for gasohol and, consequently, those vehicles that were operating in a richer than necessary condition for gasoline would be leaned by the alcohol and experience some improvement in mileage. Vehicles operating at the stoichiometric air-fuel mixture for gasoline would be overly leaned by the gasohol and experience some hesitation that could lead to a reduction in mileage.⁽⁵⁹⁾ Vehicles with closed-loop fuel systems would not likely be affected by the leaning effect of the alcohol in the gasohol.^(60,61)

The depression in the distillation curve caused by the addition of alcohol to gasoline conceivably could cause an improvement in starting performance, but it could also cause an increase in vapor lock and evaporative losses and a deterioration in warm-up driveability. Therefore, it is difficult to determine if the effect of the depression on miles per gallon is positive or negative. The higher Reid vapor pressure would result in an increase in evaporative losses that should show up in mileage figures. The higher flammability limit of gasohol could result in improved combustion in certain situations and thereby provide an improvement in mileage.

The net effect on mileage is most certainly a result of a combination of factors, with the lower heating value and increased volatility of gasohol causing a reduction, and the higher octane, the leaning effect of the alcohol, the increased volatility (as it contributes to winter starting performance) and the increased higher flammability limit tending to improve mileage. The net result is a function of the characteristics of the vehicle, the vehicle operating conditions, and the relative influences of the various factors. The results of the fuel consumption comparisons suggest that on the average the heating value is the overriding characteristic of the fuel, and that other characteristics tend to cancel one another or are negligible for most vehicles. In general, the vehicles manufactured after 1976 got marginally better mileage than would be expected based on the heating value of gasohol, and the older vehicles got marginally worse mileage. Possible explanations are that the newer vehicles benefited more from the higher octane of the gasohol and the older vehicles probably suffered more from hesitation caused by leaning and from evaporative losses.

The changes in fuel characteristics resulting from the addition of alcohol to gasoline affect air quality. The leaning effect of the alcohol provides a reduction in carbon monoxide emissions, but the hydrocarbon and nitrogen oxide emissions may be increased or decreased depending upon the calibration of the carburetor.⁽⁶²⁾ For new model vehicles with closed-loop fuel systems, the effect of leaning on emissions should be negligible.^(63, 64) The higher volatility of gasohol causes an increase in evaporative emissions from the vehicle and bulk storage so that the net effect of gasohol on air quality is negligible. Isolated improvements or

deteriorations in air quality would be expected. In the future, vehicles will be equipped with closed-loop fuel systems so that improvements resulting from leaning will likely be negligible. The anticipated use of devices to control evaporative emissions from vehicles and equipment and a reduction in the volatility of the base gasoline will likely eliminate the detrimental effect of higher evaporative emissions from gasohol. The net effect on air quality that can be attributed to gasohol is likely to be negligible.

It has been suggested by some people that major improvements in air quality have occurred in Brazil as a result of an increase in the use of alcohol relative to gasoline. To put the Brazilian situation into perspective, it must be realized that vehicles in Brazil have been deliberately tuned rich so they will perform adequately on fuel containing high percentages of alcohol.⁽⁶⁵⁾ During periods when less alcohol was available due to seasonal fluctuations in alcohol production these vehicles were operated on gasohol containing approximately 5% alcohol, a fuel mixture that was excessively rich, and the exhaust emissions naturally contained high concentrations of carbon monoxide and hydrocarbons.

Another interesting feature of the situation in Brazil is the low octane number of gasoline there. Typically, their gasoline has a motor octane number of 73, and the addition of 20% alcohol increases the number to 81,⁽⁶⁶⁾ which represents a substantial and necessary increase. The octane of gasoline available in this country is acceptable for a majority of the vehicles on today's market, so it's not appropriate to claim a major benefit for the addition of alcohol. However, it has been suggested that one of the greatest potential means for achieving energy conservation in this country, as pertains to the use of gasohol, is to save energy and money at the refinery level by producing a low octane gasoline and subsequently adding alcohol to bring the octane up to acceptable levels. A recent report suggests that the equivalent of 0.27 to 0.45 gal. of gasoline can be saved at the refinery level for each gallon of alcohol used to raise the octane of a low octane gasoline to acceptable levels.⁽⁶⁷⁾ Another action that can be taken at the refinery level is to produce a low volatility gasoline, which would tend to offset the increase in volatility and the corresponding increase in evaporation losses that occur as a result of adding alcohol to gasoline. Actions at the refinery level such as these could radically affect the cost and value of gasohol.

With respect to the effect of gasohol on vehicle maintenance and service life, no significant changes in requirements have been reported. No fleet-wide problems developed during the test reported here. However, it must be remembered that most technical literature suggests that there is a tendency for an increase in the wear and deterioration of some vehicle components for operation on fuels

containing alcohol. The probability for damage increases as exposure to alcohol increases. Whereas long-term fleet tests may identify more specific problems, it is likely that they can be properly handled by modern technology. As with any changing technology, it will be necessary to keep abreast of developments to minimize the cost of transition.

It is believed that with a reasonable knowledge of gasohol, this fuel can be satisfactorily handled and stored using equipment and procedures applicable to gasoline. Special attention need be directed only to water contamination, evaporative emissions, and equipment specifically designated by manufacturers as being unacceptable for use with fuels containing alcohol. Similarly, the alcohol can be satisfactorily handled by paying particular attention to the requirements for special equipment, avoiding water contamination, and being aware of the need for special fire protection.

In essence, the gasohol available on today's market has many of the shortcomings that would be expected from a fuel introduced for use in vehicles carefully designed to operate on gasoline. At present, its use can't be justified on the basis of cost, net improvements in air quality, or net improvements in mileage. However, gasohol is an acceptable alternative to gasoline and can be used to reduce gasoline consumption by approximately 7% to 8%. A specially prepared gasohol will likely surface in the years ahead or other technology will be applied that will eliminate the shortcomings of today's gasohol and thereby provide improvements in energy use. The use of 100% alcohol in vehicles specifically designed to utilize its unique properties may prove to be the greatest improvement.

CONCLUSIONS

1. The differences between gasohol and gasoline have measurable effects on handling and storage requirements and the operation of vehicles.
2. With respect to handling and storage requirements, special attention should be directed to filter plugging, water contamination, evaporative emissions, and equipment that may deteriorate prematurely due to the presence of alcohol in the fuel.
3. Similar considerations apply to the maintenance of vehicles and equipment.
4. For the most part, the drivers in the fleet test perceived gasohol and gasoline to be similar, with the exception of a definite preference for gasohol from the standpoint of a reduction in engine ping due to the higher octane of the gasohol.
5. Gasohol does not provide a net improvement in air quality, because improvements in exhaust emissions are offset by increases in evaporative emissions.
6. For most vehicles, gasohol provides a 2% to 3% reduction in miles per gallon because of its lower heating value.
7. The use of gasohol at today's prices would increase fuel costs by 11% to 12% as compared to operation on gasoline.
8. Gasohol can be satisfactorily used to reduce gasoline consumption by 7% to 8%.

RECOMMENDATIONS

1. On the basis of economics, a switch from gasoline to gasohol cannot be recommended at this time.
2. A switch from gasoline to gasohol can be recommended, if —
 - (a) gasoline cannot be obtained
 - (b) gasohol becomes cheaper than gasoline, or
 - (c) the overwhelming concern of the Department is to reduce gasoline consumption.
3. The Department should keep abreast of developments pertaining to gasohol so that cost-effective decisions can be made in the future.

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