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TESTING OF A 10% ETHANOL - 90% GASOLINE MIXTURE FOR AUTOMOTIVE FUEL*

by

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INTRODUCTION

The proposal that ethanol be used as a blending component in automotive fuels is almost as old as the automobile itself. In 1907 for example, the U.S. Department of Agriculture published a report entitled "Use of Alcohol and Gasoline in Farm Engines." Over the intervening years many laboratory tests on the performance of stationary automobile engines operating on ethanol-gasoline mixtures have been reported in the literature but prior to 1975 there were no reports in the literature of any fleet tests of ethanol-gasoline mixtures. Contact with automotive and petroleum companies indicated that they too knew of no such comprehensive tests. Because of the knowledge to be gained from such a program, the author planned and directed a two million mile road test program using a mixture of 10% anhydrous ethanol - 90% unleaded gasoline as one fuel and unleaded gasoline as the control fuel. This program was carried out under a grant from the Nebraska Agricultural Products Industrial Utilization Committee with the cooperation of the Nebraska Department of Roads. Testing began on December 23, 1974 and was completed on October 31, 1977. Approximately 60 vehicles participated in the test program.

In Nebraska, we refer to a blend of 10% anhydrous ethanol - 90% unleaded gasoline as GASOHOL. For the sake of convenience I will use this name here also. The GASOHOL fuel used in the test was blended for us by the Cooperative Refiners Association in Phillipsburg, Kansas. The no-lead base gasoline used in the preparation of the GASOHOL is the same no-lead which they market through their normal channels.

The objectives of the GASOHOL Road Test Program were to gather:

A. Quantitative information on:

1. Fuel consumption.

2. Cylinder wear.

3. Exhaust gas composition.

B. Qualitative information on:

1. Valve and valve seat condition.

2. Spark plug condition.

3. Exhaust system condition.

In addition to the above information, we solicited drivers' comments on the performance of GASOHOL and unleaded fuel in their particular vehicle.

All vehicles tested had eight cylinder engines. Spark plug numbers three and six were removed from the engine every 90 days, examined for deposits and general condition and photographed for record purposes. While the spark plugs were removed compression was checked on the two cylinders.

Cylinder wear and valve seat conditions were also checked every 90 days by removing the heads from 10 of the test vehicles. The cylinder diameter was measured in each cylinder for each vehicle and a record kept of these measurements. Valves and valve seats were examined visually and photographed to provide a permanent record.

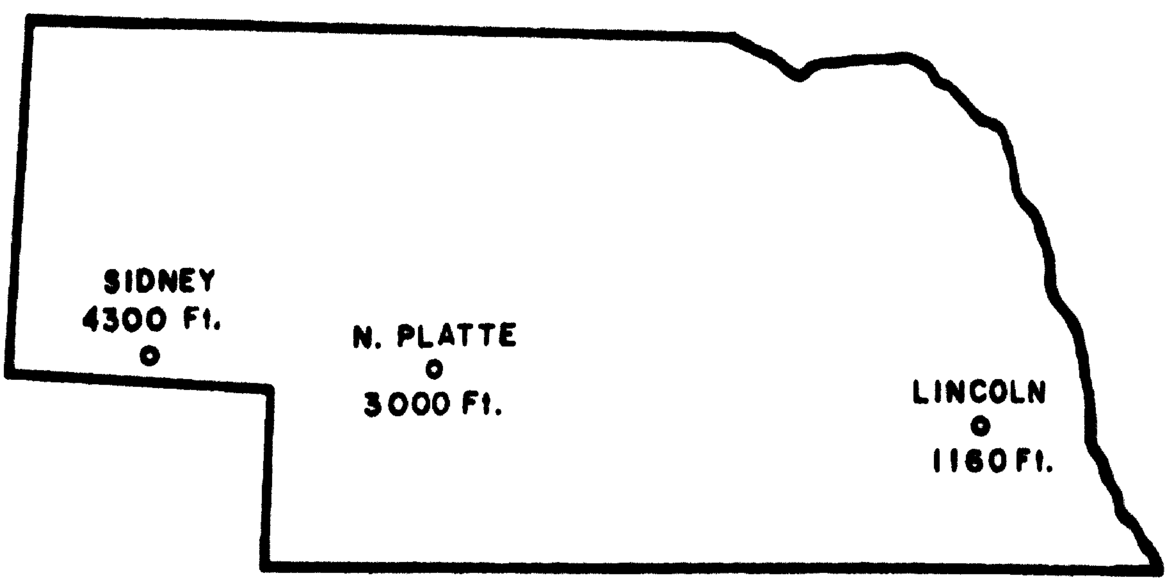
Quantitative information on the fuel consumption was obtained from weekly reports of odometer readings on each vehicle and fuel additions to the gas tank. Figure 1 shows the location of the three GASOHOL fuel tanks in Nebraska. In the eastern part of the state is Lincoln at an elevation of 350 meters. At Lincoln we have an 11,000 liter buried fuel tank and pump for GASOHOL fuel. During the test program 24 vehicles obtained their fuel here. Those vehicles on no-lead fuel purchased their fuel commercially at local stations. Approximately 375 kilometers west of Lincoln is North Platte at an elevation of 915 meters. At North Platte we have a 19,000 liter buried tank and a fuel pump which supplied GASOHOL fuel to seven vehicles operating in that area. Approximately 185 kilometers west of North Platte, at an elevation of 1,310 meters is Sidney, Nebraska. They too have a 19,000 liter buried tank and pump which supplied four vehicles with GASOHOL fuel. We chose three sites at different elevations in order to determine whether there are any unusual altitude effects associated with the use of GASOHOL fuel.

PROPERTIES AND PERFORMANCE OF GASOHOL

Ethyl alcohol and gasoline are miscible in all portions. The presence of the alcohol in solution with gasoline also increases the water tolerance of the gasoline. Gasoline itself will hold only a few parts per million of water whereas a 10% mixture of ethanol and gasoline will tolerate upwards of 0.35% water (depending upon temperature) before phase separation takes place. Thus, if normal precautions are taken in the refinery, during transportation, and at the service station the use of an ethanol-gasoline blend will insure the driver

FIGURE I

NEBRASKA GASOHOL
TEST STATIONS



of a completely dry fuel system in his vehicle. To insure that water levels remain low in the fuel throughout the various stages of blending and handling we recommend the use of anhydrous ethanol as the alcohol component. Almost three year. of experience incl .ding severe wi. ter conditions at temperatures as low as -35°C have been encountered in our Nebraska Two Million Mile GASOHOL Road Test Program with no problems encountered from water phase separation.

Octane number is an important property of automotive fuel. Ethanol is a component which as a pure component has an F-1 (research) octane number of about 106. However, in solutions of low concentrations ethanol displays an even higher blending octane number. At 10 liquid volume per cent ethanol in unleaded gasoline this blending octane number is 134 on the F-1 scale. Figure 2 shows the results of a number of octane measurements as a function of liquid volume per cent ethanol in the unleaded fuel. The scatter of the data points is within the precision of the octane measurement method. At the level of 10 liquid volume per cent ethanol the F-1 octane number of the alcohol-gasoline blend will be 4.2 numbers higher than the unleaded base gasoline used in the blend. The F-2 (motor method) octane number is also increased by about 1.5 numbers. This ability to increase octane number adds value to the ethanol because it permits a less costly base stock to be used for blending GASOHOL fuel of an octane number equivalent to unleaded fuel which is normally marketed.

A second interesting phenomena that has been found in blending GASOHOL fuel is that anhydrous ethanol and gasoline display a positive volume change on mixing at alcohol levels below about 16 liquid volume per cent. Figure 3 shows the effect of ethanol content on mixture expansion. At 10% ethanol the mi ture expands by abc t 0.23% while he maximum expansion occurs at about 12.5% ethanol and is equal to approximately 0.55%. Additional ethanol in the alcohol-fuel blend can not be justified economically on the basis of the expansion difference between the 10% and 12.5% concentrations.

The normal boiling point of ethanol (78.3°C) is sufficiently high that it has little or no effect on the vapor pressure and front end volatility of the unleaded gasoline used in blending GASOHOL. Numerous measurements have been made on unleaded base stocks and GASOHOL blends and it has been found that the Reid vapor pressure remains the same when the ethanol is added. The ASTM D-86 distillation is considered by the petroleum industry to be an important indication of the vaporization characteristics of automotive fuel. Figure 4 is a typical D-86 distillation for unleaded gasoline used as the base stock for GASOHOL fuel and for the GASOHOL fuel itself. Both fuels have the same volume per cent distilled verses temperature relationship for the first 5% of the distillation. This supports the observation that little vapor pressure change is found when blending GASOHOL. Beyond the 5% point and up to approximately

FIGURE 2

EFFECT OF ETHANOL ADDITION ON THE F-1 OCTANE NUMBER OF UNLEADED FUEL

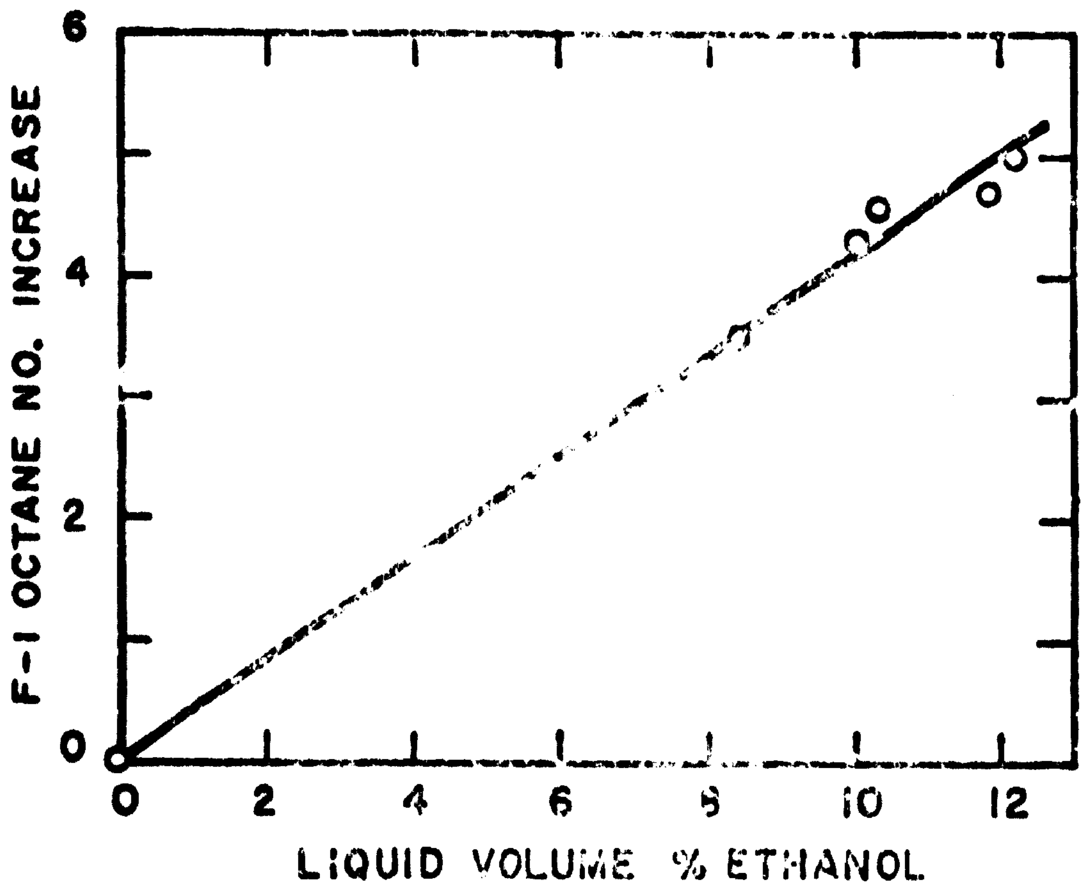


FIGURE 3

VOLUME CHANGE OF MIXING FOR
ETHANOL-GASOLINE BLENDS

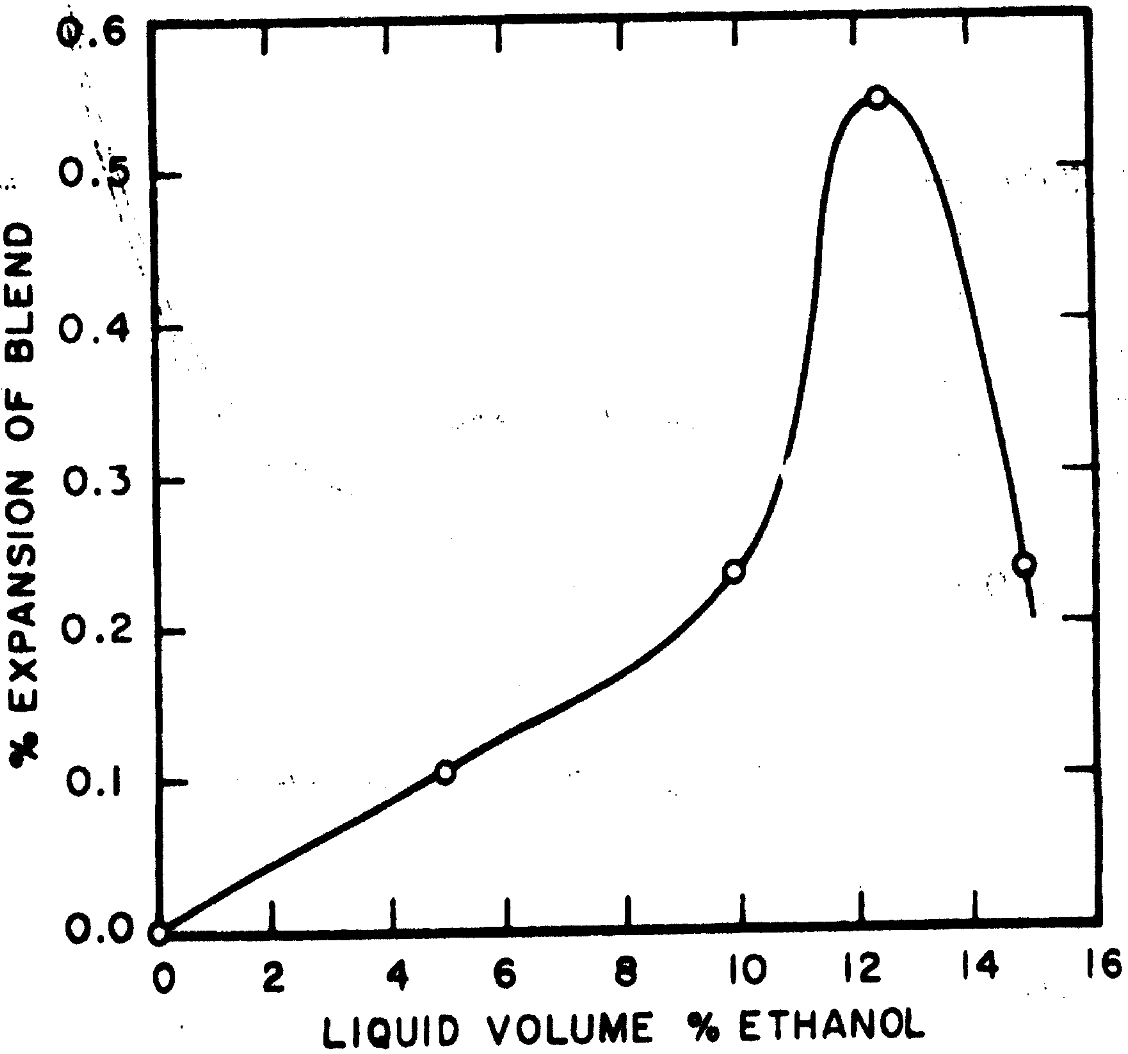
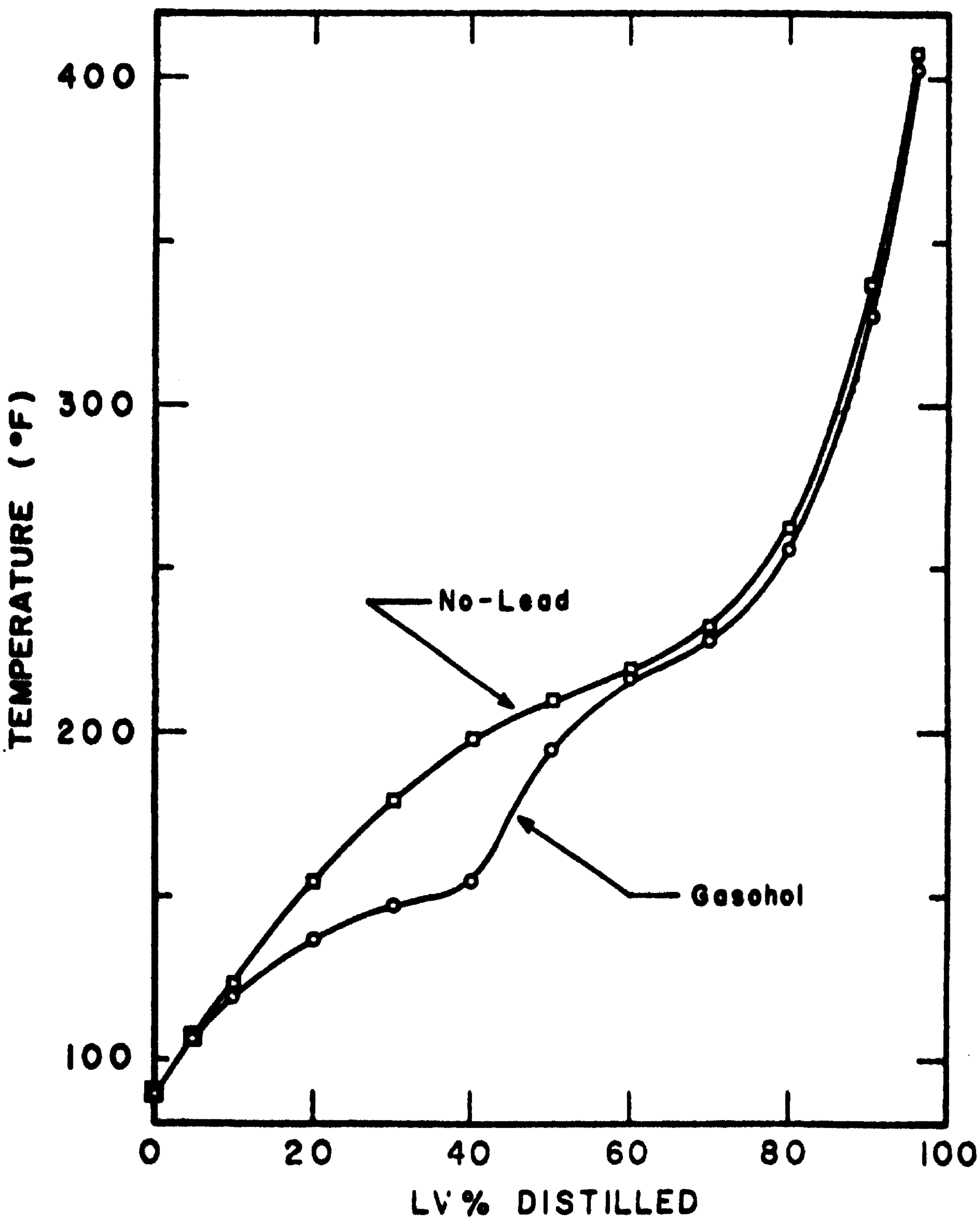


FIGURE 4

ASTM D-86
DISTILLATION



60% distilled the GASOHOL fuel shows a lower distillation temperature (higher volatility) than the unleaded base stock. Beyond 60 liquid volume per cent distilled the two distillation curves can again be considered to be identical. Drivers of the GASOHOL test vehicles have reported good performance with this fuel and also indicated good starting especially in winter months. On the other hand during the summers when the drivers have encountered temperatures of 100°F and higher during the day they have not experienced any vapor-lock problems even at altitudes close to 1,500 meters. It is believed that the lack of vapor-lock problems is the result of the front end (up to 5 liquid volume per cent distilled) of the distillation curves being identical for the two fuels. On the other hand, the improved performance and starting in the winter months is believed to be the result of the more volatile nature of the GASOHOL fuel between the 10% and 60% distilled points giving more efficient carburation and more complete vaporization of the fuel with better distribution in the intake manifold. Table I contains typical inspections of an unleaded gasoline and a GASOHOL fuel containing 11.8% anhydrous ethanol.

TABLE I

INSPECTION OF
GASOLINE AND GASOHOL

Inspection	ASTM Test	No-Lead	GASOHOL
LV% Ethanol	---	0	11.8
API Gravity	D-287	69.1	56.5
Reid Vapor Pressure	D-323	12.0	11.3
Copper Strip	D-130	1-A	1-A
Saturates (LV%)	D-1319	85.0	---
Olefins	D-1319	1.5	---
Aromatics	D-1319	13.5	---
Research Octane No.	D-2699	92.9	97.7
Motor Octane No.	D-2700	87.0	88.2
(R+M)/2 Octane No.	---	90.0	93.0
Gross Ht. of Combust.	D-240	20,359	19,468 Btu/Lb

As mentioned previously a Two Million Mile Road Test for the comparison of GASOHOL fuel with unleaded gasoline was completed on October 31, 1977. Engine inspections, valve inspections, spark plug inspections, compression ratios, cylinder wear measurements, etc. indicate no unusual wear or deterioration of the engine as a result of using the GASOHOL fuel. Data on fuel consumption and miles travelled have been key punched and computer programs are being prepared for a complete analysis of the data. Figure 5 contains results for the vehicles in the test run operating from the North Platte, Nebraska office of the Department of Roads. In an effort to cancel out the effect of varying weather conditions we have plotted the ratio of the average number of miles travelled in a reporting period per test car using GASOHOL fuel to the average number of miles travelled in the same period per test car using unleaded fuel. On the y axis is plotted the ratio of the GASOHOL fuel consumed in the reporting period per test car to the unleaded fuel consumed per test car in the same period. The data shown cover a period of approximately 1.5 years. Since data were not available at exactly one week intervals and since there were some weeks when insufficient data were available, there are a total of 45 data points.

The point of interest in Figure 5 is that at which the mile ratio is equal to 1. It is at this point that we have the equivalent consumption of GASOHOL fuel relative to no-lead fuel. I have drawn a dashed line on the chart to represent equal rates of fuel consumption. The solid line on the chart is the best fit of a quadratic equation passing through the origin (0,0). This best fit indicates that at an equal number of miles travelled the GASOHOL cars consume about 6.7% less fuel than the cars operating on unleaded gasoline. Applying Wilcoxon's signed ranks test to the data indicates that there is a 99 + % probability that the GASOHOL cars are consuming less fuel than the test cars operating on unleaded gasoline.

The fuel consumption of the Lincoln based GASOHOL cars and the cars using unleaded fuel have been compared at four different temperatures over a two year period. It has been found that at temperatures below about 19.4°C the vehicles using GASOHOL travel more miles on a gallon of fuel than the control vehicles using unleaded gasoline. When expressed as miles per Btu consumed the GASOHOL shows higher efficiency than unleaded fuel at all temperatures.

Figure 6 illustrates these effects. On the y axis is plotted the percent increase in miles per gallon or miles per Btu for the GASOHOL fueled cars compared to the cars using unleaded fuel. For example, at 45°F (7.2°C) the GASOHOL cars obtained about 5.3% more miles per gallon or 8.7% more miles per Btu than the control vehicles running on unleaded gasoline. The square data point at 75°F (24°C) in Figure 6 represents a composite of simulated urban and highway driving data obtained according to EPA standard test procedures with two Lincoln, Nebraska, test cars at the Bartlesville, Oklahoma, Energy

FIGURE 5

CONSUMPTION OF GASOHOL FUEL RELATIVE TO NO-LEAD AT NORTH PLATTE, NEBRASKA

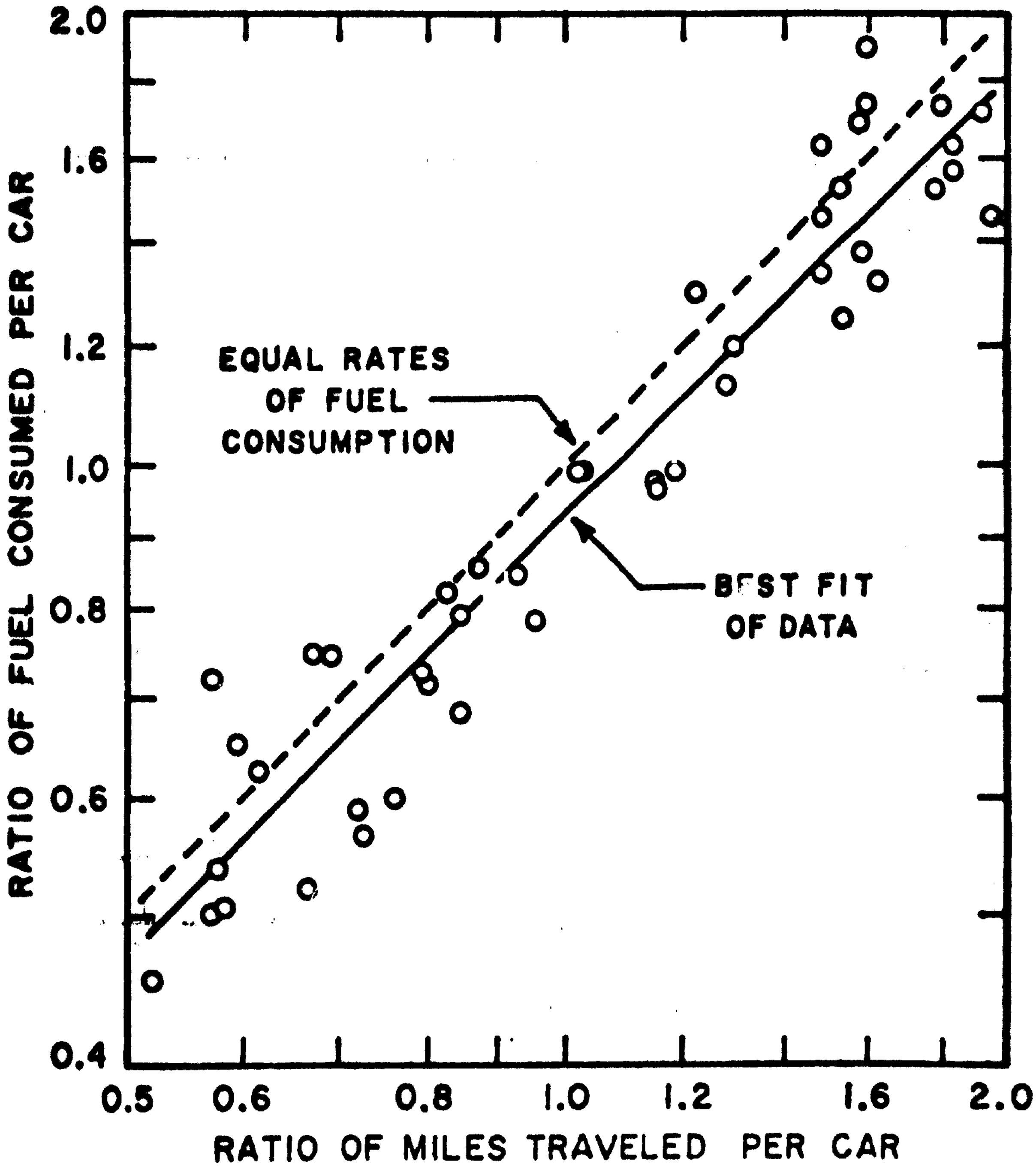
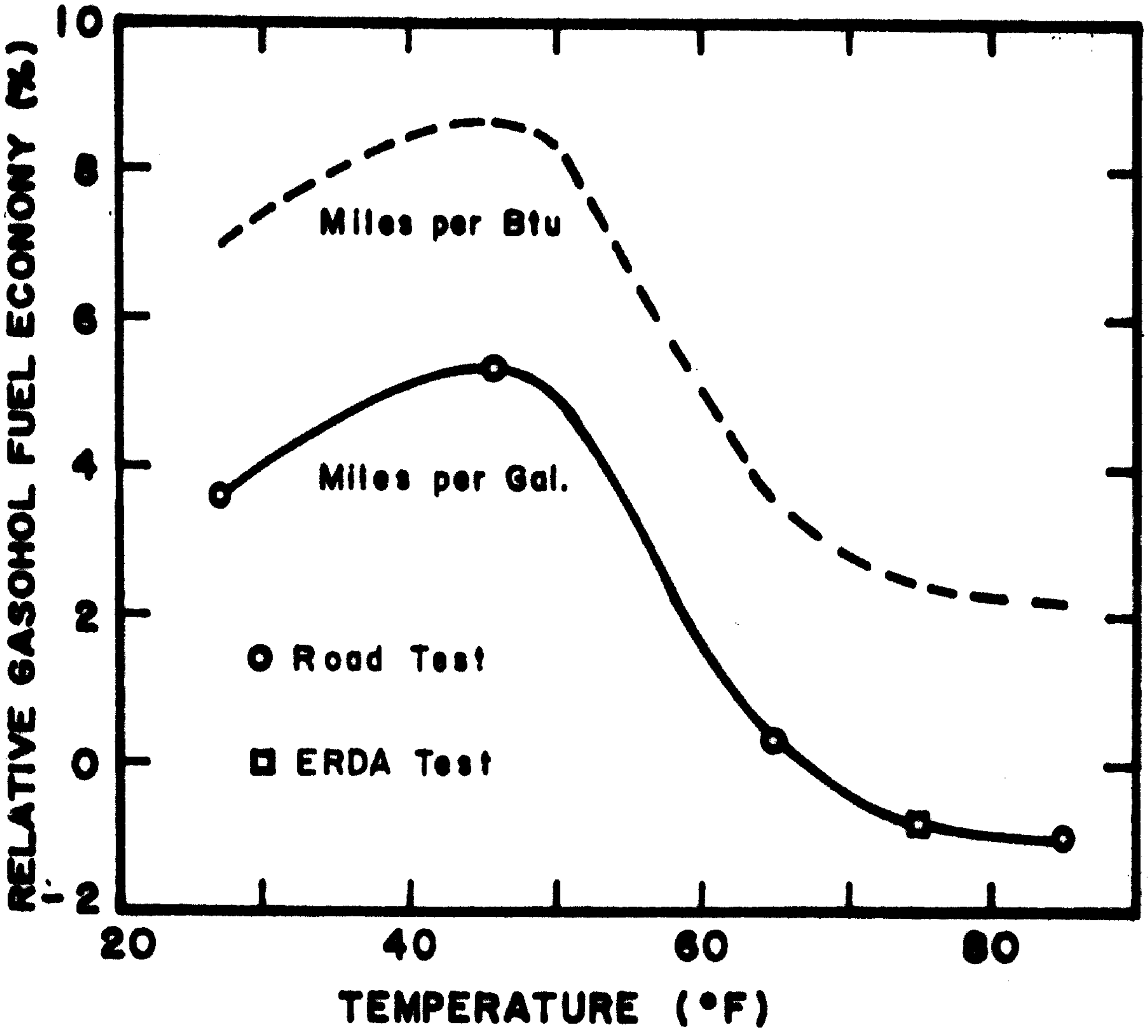


FIGURE 6

EFFECT OF TEMPERATURE ON RELATIVE FUEL ECONOMY OF GASOHOL TO NO-LEAD



Research Center of ERDA. This point appears to be consistent with the data obtained from the Two Million Mile Road Test program.

In addition to the fuel consumption tests mentioned above, analyses of exhaust gases from the two test vehicles were also obtained by the ERDA Energy Research Center according to standard procedures. Table II contains a summary of the emissions compositions and the fuel consumptions. These data indicate that GASOHOL fuel produces emissions containing less CO and about equal amounts of NO_x and unburned hydrocarbons. The total emissions for GASOHOL are somewhat less than for unleaded gasoline.

The figures shown in Table II for car 53003 are the average of three tests for each fuel and those for car 53000 are for two tests for each fuel. The cars tested were 1973 AMC Ambassador Sedans with 360-CID V-8 engines and automatic transmissions. Car 53000 registered about 72,000 miles (116,000 km) on the odometer and car 53003 registered about 67,000 (108,000 km). Both cars were a part of the 2 million mile road test since its initiation in December 1974.

CONCLUSIONS

As a result of this study it appears that there are at least four factors which make alcohol a desirable component for blending with unleaded automotive fuel. These are increased octane number resulting from alcohol addition, positive volume change of mixing, reduced fuel consumption with GASOHOL fuel compared to unleaded fuel and fewer pollutants in the engine exhaust. In addition the improved volatility of GASOHOL fuel provides added driver satisfaction through easier starting of the vehicle especially in cold weather.

TABLE II

Summary of ERDA Emissions and Fuel Consumption Tests at 75°F (24°C)

	Gm/Mi					
	Car 53003		Car 53000		2 Car Average	
Component	GASOHOL	No-Lead	GASOHOL	No-Lead	GASOHOL	No-Lead
CO	15.4	23.1	25.9	38.1	20.7	30.6
HC	1.8	2.0	2.8	2.7	2.3	2.3
NO_x	2.4	2.7	2.1	1.8	2.3	2.3
Subtotal	19.6	27.8	30.8	42.6	25.3	35.2
CO_2	751.9	768.9	658.7	653.4	705.3	711.1
Total	771.5	796.7	689.5	696.0	730.6	746.3
Fuel Consumption						
Urban Mi/Gal	10.4	10.4	11.5	11.7	10.9	11.0
HWY Mi/Gal	15.1	15.5	16.3	16.7	15.6	16.1
Combined Mi/Gal	12.1	12.2	13.3	13.5	12.7	12.8

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