INVESTIGATION OF THE USE OF METHANOL-GASOLINE BLENDS

by

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Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

An 18-month field test was conducted to determine if the Virginia Department of Highways & Transportation should give serious consideration to the use of methanol as a substitute for gasoline in the operation of its motor vehicles. Five of the eight 1973 and 1974 model vehicles involved in the test were operated for a total of 92,000 miles on a fuel blend containing an average of 10.7% methanol and 89.3% lead-free gasoline. The fuel was dispensed from a commercial type gasoline blending pump by blending at the nozzle and by pumping directly from a storage tank containing a specified blend of methanol and gasoline.

The vehicles operating on the blend averaged 4.0% fewer miles per gallon but were 1.3% more efficient from a miles/Btu standpoint than the vehicles operating on lead-free gasoline. Exhaust emissions data suggested that emissions are more dependent on carburetor adjustments than on the percentage of methanol in the fuel. Driveability was impaired enough in two of the vehicles operating on the blend to warrant carburetor modifications before the vehicles could be operated safely and satisfactorily because the addition of methanol made the fuel-air mixture too lean for good engine performance and because the methanol was incompatible with certain fuel system parts. Since methanol and gasoline are not completely miscibile at all temperatures and moisture conditions, a major effort was required to properly store and dispense the desired blend. From a consideration of economic and supply factors, it was concluded that the use of methanol-gasoline blends in Department vehicles would not be justified at this time. Implementation would require that special attention be directed to vehicular adjustments and to the storage and handling of the blends.

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INTRODUCTION

Although the idea of using alcohol as fuel is as old as the internal combustion engine,[1,2,3] interest has recently been revived because of the clean burning characteristics of alcohol[4,5] and because of the rising price and diminishing supply of gasoline. But information on the use of alcohol and alcohol-gasoline blends as fuel for motor vehicles is somewhat inconsistent and controversial. Opponents of their use claim that alcohol causes corrosion of the engine and fuel system parts, deterioration of gaskets and seals, unacceptable vehicle performance, and problems in handling and storing of the liquids.[2] On the other hand, proponents say that alcohol reduces vehicle emissions, improves fuel mileage and vehicle performance, and offers an immediately available substitute for gasoline.[1,3,5] According to the United States Energy Research and Development Administration, alcohol, particularly methanol, may provide for the expansion of domestic fuel resources in the near future, but its use may be restricted to fleet vehicles.*

PURPOSE

The purpose of the investigation reported here was to determine, in light of the fuel crisis and the controversy concerning the acceptability of alcohol as a substitute for gasoline, if methanol deserves serious consideration for use as a substitute for gasoline in motor vehicles operated by the Virginia Department of Highways and Transportation. The specific objectives were to enable the Department to gain experience in handling and using methanol and methanol-gasoline blends; to gather information on vehicle performance with respect to fuel consumption, exhaust emissions, driveability, and wear and deterioration of the engine, fuel system, and exhaust system parts; and to keep abreast of research on the use of alcohols as motor vehicle fuel.

*Personal communication from John J. Brogan, July 1975.

METHODOLOGY

The field investigation was centered at the Staunton District fueling area, where two 1,500-gallon fuel oil tanks and a blending pump were installed. One thousand gallons of methanol were purchased at a cost of $0.56 per gallon and stored in one of the two tanks. During the summer months a blending pump was used to blend 15.5% methanol by volume with lead-free gasoline pumped from a second storage tank. Because the pump would not blend smaller concentrations of methanol with the gasoline, during the winter months the desired blend of methanol and gasoline was prepared about each six weeks and stored in a second storage tank. To minimize separation of the methanol and gasoline due to temperature, the concentration of methanol was reduced from the maximum concentration of about 15.5% in July to a minimum concentration of about 6.8% in January. On the average a concentration of 10.7% methanol was used in the blend furnished the test vehicles during the 18-month investigation, which commenced on August 28, 1975.

Prior to the test, eight vehicles (four pairs) were inspected and tuned. The engines of one pair were disassembled, the parts examined and photographed, the cylinder walls measured, and a valve job performed. During the fuel test the eight vehicles were inspected periodically and the drivers recorded fuel and oil issue information at each fueling stop. The vehicles involved were four 1973 Plymouth Fury II's, two 1974 American Motors Matadors, and two 1974 Dodge pickup trucks. The vehicles were driven, fueled, maintained, and inspected by Staunton District personnel. The Central Office Equipment Division assisted with the analysis of the exhaust emissions. One vehicle in each pair was operated on the blend and the other on the customarily used lead-free gasoline. For the 1974 Matadors, the fuel types were reversed in April 1976. Although operating the vehicles on high concentrations of methanol or straight methanol would have provided the greatest change in fuel consumption and exhaust emissions, and likely eliminated fuel separation, the test program was directed to the use of small percentages of methanol since it was felt that small percentages would be easier and more economical to use on a large scale; the majority of the literature indicated that modification of the vehicles was not required for operation on blends of approximately 10% methanol.

RESULTS

It seems appropriate to present and discuss the study results under three headings reflecting the three objectives pursued in the 18-month investigation. Vehicle performance with respect to fuel consumption, exhaust emissions, driveability, and wear and deterioration of the engine and fuel system parts is discussed first. Next is a discussion of the experience gained in handling and dispensing methanol-gasoline blends. Current literature on the relative merits of producing and using methanol and ethanol as motor vehicle fuel concludes the results section.

Vehicle Performance

Fuel Mileage

During the 18-months of the field study, the drivers of the test vehicles recorded the date, speedometer reading, and number of gallons of blend or lead-free gasoline received. The data, which were turned over to the principal investigator after each series of 17 fueling stops, are shown in Figure 1. Vehicles B, C, and D were operated on lead-free gasoline and vehicles F, G, and H were operated on the blends at the percentages shown at the top of the figure. Vehicles A and E were operated for the first 7 months on lead-free gasoline and the blend, respectively, and then the fuel type was switched for these two vehicles.

The average quantity of methanol used in the blends was 10.7% by volume. Since a gallon of methanol has only 51.0% the energy of a gallon of gasoline, an energy calculation was made. It revealed that when the fuel was burned at the same degree of efficiency with respect to its Btu content, vehicles operating on 10.7% methanol should average 94.8% the fuel mileage of vehicles operating on lead-free gasoline. The study showed that the average fuel mileage over the 18-months for the vehicles operating on the blend was 96.0% of that for the vehicles operating on lead-free gasoline. Therefore, based on the Btu contents of the fuels, on the average the test vehicles burned the blended fuel 1.3% more efficiently than they did the lead-free gasoline. Some of the test vehicles operating on both the blend and the lead-free gasoline operated at efficiencies better or worse than the average as shown by Table 1. The blend was used in five vehicles for a total of 92,084 miles over the 18-months; the lead-free gasoline in five vehicles for 139,659 miles.

It is encouraging to note that the fuel consumption per mile for vehicles A and E appeared to be about the same when the vehicles were operating on the blend as when they were operating on the lead-free gasoline. The type driving may have had a slight influence on the mileage of the study vehicles and unfortunately, as is shown in Table 1, the vehicles operating on the blend generally were driven fewer miles during the 18-month period than were

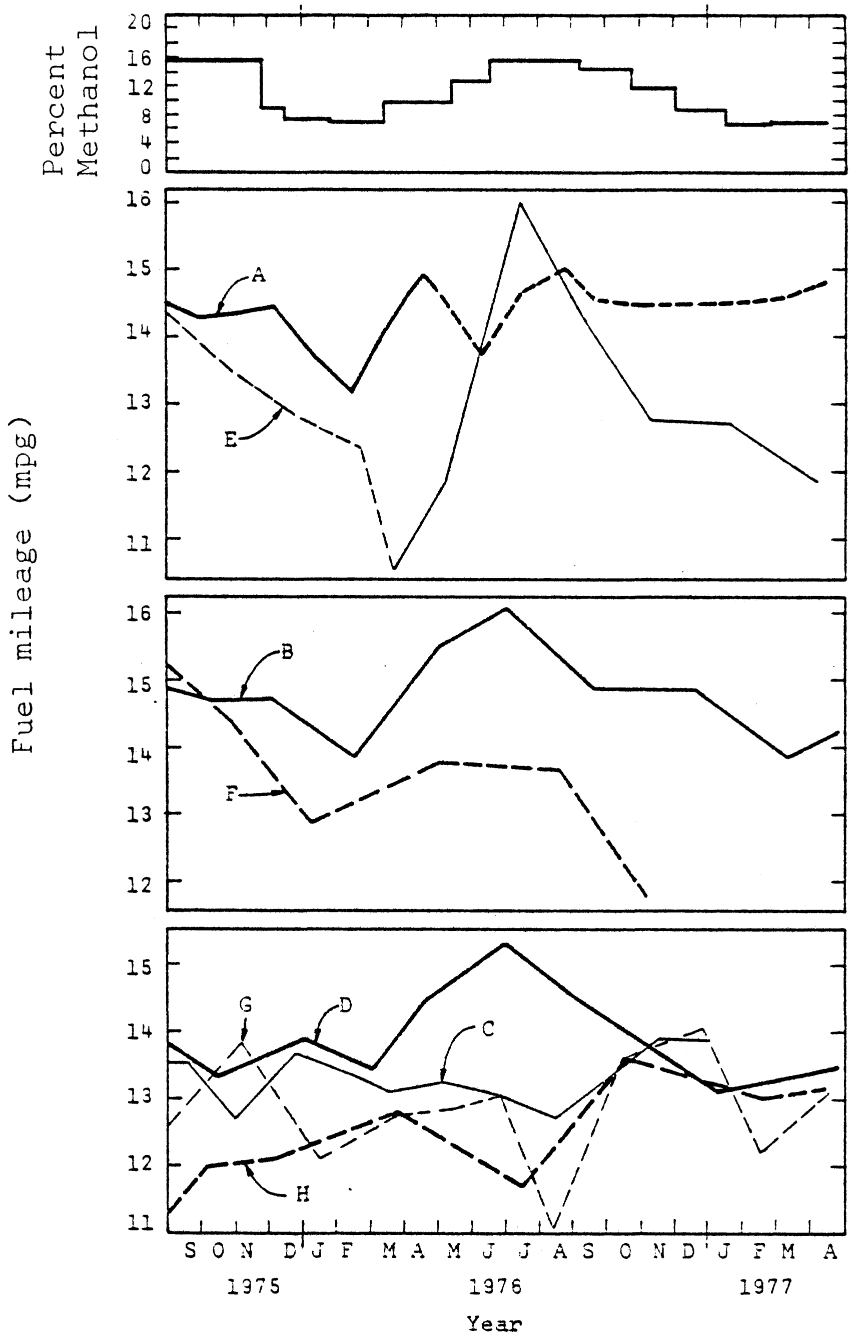

Figure 1. Miles per gallon achieved over study period. Dashed line represents blend; solid line lead-free gasoline.

Table 1

Fuel Mileage for Test Vehicles

Vehicle Designation	Make	Year	Type Fuel	Miles Driven		Fuel Mileage	
				Per Week	Total	Average mpg	Relative: Blend/Lead-Free
A	Matador	1974	Lead-Free	753	27,877	14.17	----
A	Matador	1974	Blend	565	28,809	14.51	1.02
E	Matador	1974	Lead-Free	214	11,535	13.32	----
E	Matador	1974	Blend	181	4,883	12.51	0.94
B	Dodge	1974	Lead-Free	376	33,800	14.73	----
F	Dodge	1974	Blend	265	16,421	13.23	0.90
C	Plymouth	1973	Lead-Free	501	37,545	13.29	----
G	Plymouth	1973	Blend	273	23,183	12.90	0.97
D	Plymouth	1973	Lead-Free	328	28,902	13.89	----
H	Plymouth	1973	Blend	226	18,788	12.77	0.92

those operating on the lead-free gasoline. The miles driven per week ranged from an average of 753 for vehicle A operating on lead-free gasoline to 181 for vehicle E operating on the blend. However, all of the vehicles were used predominately for travel on interstate or primary roads and the difference in the miles driven per week reflects differences in trip length and the number of days the vehicles were used. The number of miles driven per week was not likely a significant factor in the vehicles operating on the blend generally getting the lower fuel mileage; when vehicle E was switched from the blend to lead-free gasoline, the fuel mileage improved but the miles driven per week remained about the same. Also the miles per gallon figure for vehicle A improved when the switch was made from lead-free gasoline to the methanol blend,but the miles driven per week decreased from 753 to 565. Finally, while vehicles D and C both used lead-free gasoline, the former, driven 213 miles per week, averaged more miles per gallon than the latter, which was driven 501 miles per week.

Figure 2 is a reproduction of a figure obtained from T. B. Reed of MIT which shows the fuel economy for vehicles and engines operated on various percentages of methanol as compared to gasoline and reported by various laboratories.(7) It is very encouraging to note that the data from the present study as reported in Table 1 agree with much of the data in Figure 2.

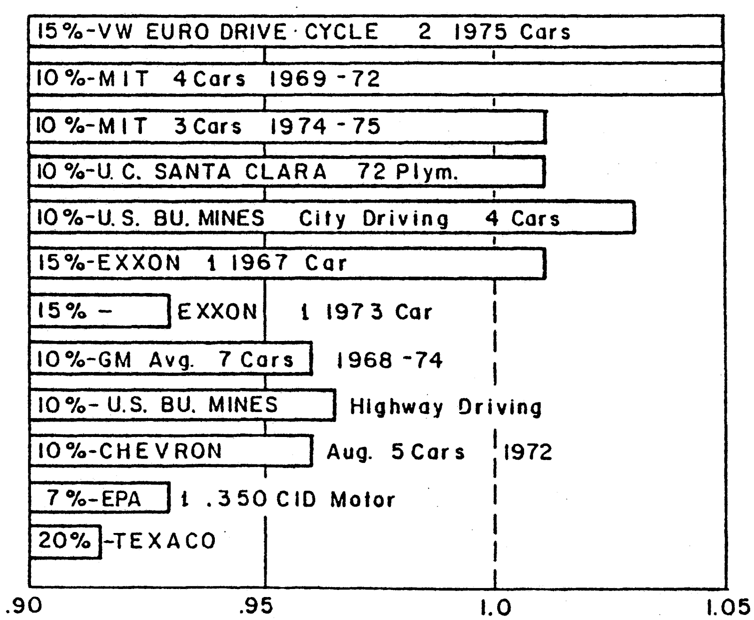

Figure 2. Fuel economy for vehicles and engines operated on various percentages of methanol as compared to gasoline and reported by various laboratories. (After Reed(7).)

Exhaust Emissions

Six of the eight test vehicles were placed on the dynamometer located at the Central Garage in Richmond, and a CO/HC infrared emission analyzer was used to analyze the exhaust emissions under various operating conditions. The exhaust of vehicles B, C, and E, which were operating on lead-free gasoline, and vehicles A, F, and G, which were operating on a blend of 12.6% methanol, were analyzed in the latter part of May 1977. The exhaust of vehicles B and F were analyzed in December 1975, when B was using gasoline and F was operating on a blend of 4.8% methanol. The emissions data are shown in Table 2.

Carbon monoxide (CO) emissions of less than 2% and hydrocarbon (HC) emissions of less than 200 ppm were considered acceptable at the time the tests were conducted. As can be seen from Table 2, vehicle F emitted excess CO when idling on 4.8% methanol and vehicle G emitted excess HC at all driving conditions when operating on 12.6% methanol. The emissions for the other vehicles were satisfactory.

In general, the 1973 model vehicles (C and G) produced more emissions than did the 1974 models. The emissions from vehicles E and A were about the same, although vehicle A operated on 12.6% methanol. Evidently the exhaust emissions are affected more by the air to fuel ratio than by the addition of methanol to gasoline. Figure 3, which was taken from a publication by N. D. Brinkman of the General Motors Corporation,[8] tends to explain the exhaust emissions data reported in Table 2. The theoretically balanced air to fuel ratio for complete combustion (point S in Figure 3) is 15.1% for gasoline and 6.5% for methanol. The addition of 12.5% methanol to gasoline produces a blend with a theoretical air to fuel ratio of 14.0. At the start of the test program vehicles B and F were probably operating on gasoline with a minimum of emissions. The addition of 15.5% methanol made the air-fuel mixture so lean for vehicle F that it would not drive satisfactorily because of hesitation and the jets had to be enlarged. Once the jets were enlarged to adjust the air-fuel mixture from 15.1% to 14.0%, this vehicle produced satisfactory emissions when operating on 12.6% - 15.5% methanol, but when the methanol content was reduced during the winter months the emissions, particularly the CO content, increased significantly because the air-fuel mixture was too rich. The carburetors on Vehicles C and G were probably set to provide slightly richer air-fuel mixtures than those on vehicles B and F when the test program was started, but when 12.6% methanol was added to the gasoline the HC emissions from vehicle G increased because the air-fuel mixture then became too lean for proper operation. Vehicles E and A were probably also operating on slightly richer mixtures than vehicles B and F at the start of the test program and the

Table 2

Exhaust Emissions Data

Driving Condition	Road Speed, mph Engine Speed, rpm Horsepower	0 700-900 0		30 1200-1400 2-3		60 2000-2600 10-12		40 1600-1800 20-22		40 1800-2000 40-43	
Vehicle	Methanol in Fuel, Percent	CO, Percent	HC, PPM	CO, Percent	HC, PPM	CO, Percent	HC, PPM	CO, Percent	HC, PPM	CO, Percent	HC, PPM
B	0.0	1.25	80	0.15	85	0.10	60	0.09	65	0.45	70
F	4.8	4.75	125	0.65	85	1.25	75	1.20	90	1.40	70
B	0.0	0.08	30	0.08	20	0.10	20	0.16	20	0.10	25
F	12.6	1.60	45	1.50	40	0.30	45	0.40	40	0.10	40
E	0.0	0.12	30	0.18	20	0.10	20	0.16	30	1.65	30
A	12.6	0.50	40	0.05	20	0.05	20	0.10	30	0.10	35
C	0.0	1.2	140	0.50	120	0.15	120	0.10	120	0.50	120
G	12.6	1.8	620	0.15	580	0.10	580	0.15	580	0.50	560

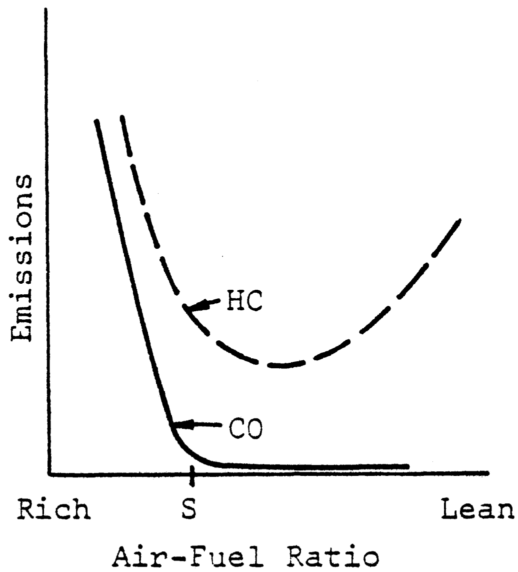

Figure 3. Well-established relationship between exhaust emissions and air-fuel ratio. (After Brinkman.[8])

addition of 12.6% methanol did not lean the fuel mixtures sufficiently to produce excess HC. Changing the percentage of methanol in gasoline from about 15.5% in the summer to 5.0% in the winter is probably not practical because of the influence of changes in percentages of methanol on the richness of the air-fuel mixture and thus emissions and driveability.

Driveability

Because fuel economy, exhaust emissions, and driveability are interrelated, comments with regard to the last of these items are meaningless without some reference to the first two.

The operation, under everyday working conditions, of four vehicles fueled with methanol-gasoline blends over a period of 18 months and for a total of 92,000 miles is evidence that the vehicles were driveable. However, it was necessary to make a trade-off between fuel economy, exhaust emissions, and driveability to complete the tests. The tests were started with unmodified vehicles and every driver complained of poor starting performance, hesitation upon acceleration, occasional stalls at stops, sluggish idle, and unsatisfactory performance in general for the vehicles fueled with blends. Drivers of two of the vehicles felt the performance was so poor that the vehicles were safety hazards; these vehicles, one the 1974 Dodge (vehicle F) and the other a 1973 Plymouth (vehicle H), were then modified. The modifications included enlarging the fuel jets to provide a satisfactory air-fuel mixture and replacing the neoprene seal in the fuel pump of the Plymouth with a leather seal. With the completion of the modifications, the drivers were pleased with the driveability of the vehicles; in fact, the Dodge drove as if it had more power than when operating on gasoline. The improvement in performance was achieved only at the cost of reducing the fuel economy and increasing the exhaust emissions.

The drivers of vehicles E and G, which were fueled with the blends, continued to live with the poor driveability, primarily because it was felt that modification of the vehicles should be avoided if at all possible. After 8 months of operation on the blends the fuel types for the pair of Matadors were reversed. With the change from the blend to regular gasoline the driveability of vehicle E changed from unsatisfactory to satisfactory; the driveability of vehicle A did not change with the switch from regular gasoline to the blend. In fact, during the next 10 months, vehicle A continued to perform as well on the blend as it had on gasoline. All the drivers of the vehicles operating on gasoline were satisfied with the driveability of their vehicles and felt they performed better than some new model vehicles. It is likely that methanol-gasoline blends would impair the driveability of new model vehicles more than reported herein.

The results of the field investigation suggest that, in general, the fuel economy achievable with blends of methanol and gasoline in the laboratory or on a test track would not be achieved in everyday vehicle use, because the driveability of the vehicles would not be acceptable unless carburetor modifications entailing a reduction in fuel economy were made.

Wear and Deterioration of Engine and Fuel System Parts

The engines of vehicles C and G were disassembled and examined prior to the start of the 18-month test and again at the completion of the test. There were more deposits on the valves and piston heads of both engines, one operating on gasoline and the other on the blend, prior to the test than after its completion. However, there was no difference in the degree of wear or deterioration of the engines at the times they were inspected. The initial buildup on the valves and pistons, which was probably caused by the lead in the gasoline used in the vehicles when they were new, was removed prior to the field test. The cleaning effect that has been attributed to the use of methanol as a fuel was not noted when the engines were torn down after 18 months of operation.

Every 3 months the plugs on all the vehicles were removed and inspected and the compression was checked to obtain a periodic indication of the condition of the engines. Again, there was no noticeable difference between the vehicles attributable to the different fuels. To keep the eight vehicles in satisfactory operating condition the engines were tuned, the plugs were changed, and deposits were removed from the valves when necessary. There was no significant difference in the amount of general maintenance required for the vehicles operating on the blend as compared to those operating on gasoline. However, the methanol reacted with the neoprene seals in the carburetor of the test vehicles and caused them to swell. The neoprene cup in the acceleration fuel pump of the two Plymouths, (vehicles H and G), had to be replaced with leather seals, and the neoprene tip on the needle valve in the carburetor of the Dodge, vehicle F, had to be replaced. Also, because methanol readily dissolves sludge and other matter which adheres to the linings of fuel storage tanks, the fuel line filters on the vehicles operating on the blend had to be replaced several times.

Metal specimens obtained from fuel tanks and fuel lines of several other vehicles were partially immersed in blends of methanol and gasoline and pure gasoline during the 18-month investigation. There was no noticeable difference in the appearance of the specimens after 18 months, except that a white residue was visible on the surface of the portion of the parts protruding above the blend. It is believed that the residue resulted from the greater evaporation and condensation of the blend as compared with the gasoline.

Storage and Handling of Fuel

Alternative Methods

A practical method for handling, storing, and dispensing the methanol-gasoline blends is necessary if they are to be used as motor vehicle fuel on a large scale. According to the literature, many of the track and laboratory evaluations of the performance of internal combustion engines operating on blends of methanol and gasoline have been accomplished by mixing small quantities of the blends in precisely calibrated burettes and dispensing the mixtures directly into the carburetors. In other performance tests the desired quantity of methanol has been put in the vehicle fuel tank prior to filling the tank with gasoline in the usual manner. Both of these methods are adequate for evaluations of vehicle performance, but are not practical for large-scale implementation.

An important part of the field test reported here was to gain experience with handling, storing, and dispensing the blends; therefore, an effort was made to operate the experimental fueling area in a manner which would lend itself to large-scale implementation.

Since methanol and gasoline are not miscible at all temperatures and tend to separate in the presence of small quantities of water, the shipment of methanol was stored in a 1,500 gallon fuel tank which had previously been steam cleaned and drained. A blending pump was obtained from a local gasoline distributor and connected to the tank containing the methanol and to a tank containing unleaded gasoline (see Figure 4). The pump was designed to dispense petroleum from each tank in 1/8 proportions having a total of nine proportion settings. A proportion setting other than one part methanol and seven parts gasoline was not used to blend fuel for the test vehicles, because it was anticipated that the vehicles would not be modified. Samples obtained periodically from the blending pump indicated that the pump was actually dispensing 15.5% methanol rather than the 12.5% it was set to provide. The precise reason for this difference was not determined. Although a blending pump that would dispense smaller percentages of methanol could probably have been obtained, its purchase was not considered practical for the following reasons.

1. The project was being conducted with an equipment and materials allocation of only $600;
2. the purpose of the project was to utilize readily available, unmodified equipment;
3. on a large scale the installation of blending pumps to provide 12.5% methanol is probably not economically practical and the use of blending pumps to provide smaller percentages would be even less practical;
4. blending at the pump could be adequately examined during the summer months when vehicle operation on 15.5% methanol was possible; and
5. an alternative dispensing technique could be evaluated during the fall, winter, and spring months when it was necessary to operate the vehicles on less than 15.5% methanol.

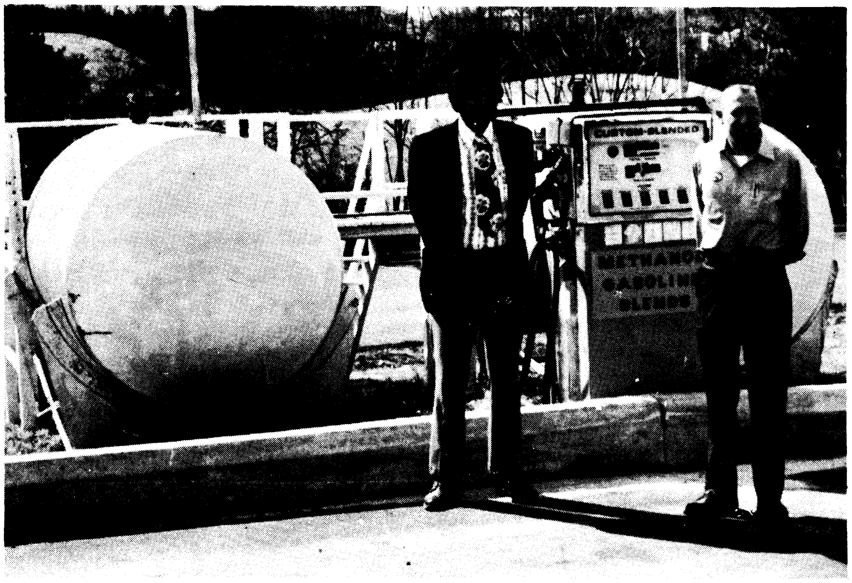

Figure 4. District personnel looked after dispensing of fuels from special installation.

The fuels were blended at the pump at the start of the 18-month test on August 28, 1975. The blending was continued until the middle of November, at which time the 15.5% methanol could not be used because the two portions of the blended fuel separated in the vehicles' fuel tanks. Consequently, it was decided that a smaller percentage of methanol would be used and the mixture would be stored in the fuel tank which had thus far contained only gasoline. About each 4 to 6 weeks a new supply of the blended fuel was prepared and stored. The concentration of methanol was gradually decreased to a low of about 6.8% in February 1976 and then gradually increased to 12.6% in May 1976 prior to switching back to blending in June (see Figure 1). Because of the lower than usual temperatures in the fall of 1976, and the fact that the vehicles did not perform well on the 15.5% methanol mixture during the previous fall, the blending at the pump was terminated toward the end of September and the system of storing the blend in one tank was implemented again.

Practical Problems

The basic problem associated with providing blends of methanol and gasoline is that the misicibility of methanol in gasoline is a function of the hydrocarbon composition of the gasoline, the temperature of the fuels, and the amount of water in the methanol. Figure 5 shows how the misicibility of methanol in typical summer and winter gasolines is affected by temperature. The basic figure was taken from reference 9 but points A, B, and C, were duplicated in the Research Council laboratory. From Figure 5, it can be seen that a 15.5% blend begins to separate when the temperature drops to 48°F. for summer gasoline and 29°F. for winter gasoline. Figure 5 reveals why separation began to be a problem in the Staunton area by the first of October and why no more than 6% to 7% methanol could be used for blends stored in January and February. Since the storage tanks were located above ground, separation in the fuel tanks of the test vehicles was not a problem, unless the fuel was blended at the pump. Since the separation would occur in the storage tank, only the percentage of methanol that could be maintained in the blend in the storage tank would be dispensed into the vehicles. On the other hand, it would be possible to maintain a blend of about 15% in an underground storage tank throughout the year because the storage temperature would stay between 40°F.and 50°F., but a blend of 15% would likely separate in the vehicles' fuel tanks if dispensed after October 1.

Figure 6 is an equilibrium phase diagram of a system of methanol, water, and gasoline. The figure was taken from reference 10, but points A and B were duplicated in the Council's laboratory. Based on tests conducted in the Council's chemistry laboratory 0.126% water will cause a blend of 12.5% methanol to separate from gasoline at 76°F. A water content of 0.126% is equivalent to 3.2 ounces of water in 20 gallons of fuel. At 40°F. only 1 ounce of water in 20 gallons of a 12.5% blend will cause separation. Because small amounts of water can cause separation, extreme care must be exercised in handling and storing blends. Separation due to water was not diagnosed as a source of trouble during the study. However, the literature indicates that water often collects in the bottoms of fuel storage tanks over a period of several years and would have to be removed if tanks seeing much service were to be used for storing blends.

Tests conducted in the Council's chemistry laboratory revealed that a blend of 12.5% methanol and gasoline evaporated faster than either pure methanol or gasoline. After 60 hours, there was 10% less fuel in a graduated cylinder containing an initial blend of 12.5% methanol as compared to an identical cylinder containing only gasoline. It was further noted that as the evaporation proceeded, some of the methanol separated, which suggests that the miscibility of methanol in gasoline is a function of the percentage of heavy volatiles in the gasoline. The increase in vapor pressure caused by combining methanol and gasoline would make it more difficult to ship and store blends than either straight methanol or gasoline. During prolonged storage the loss of the more volatile components would cause separation and result in the formation of sludge in the bottom

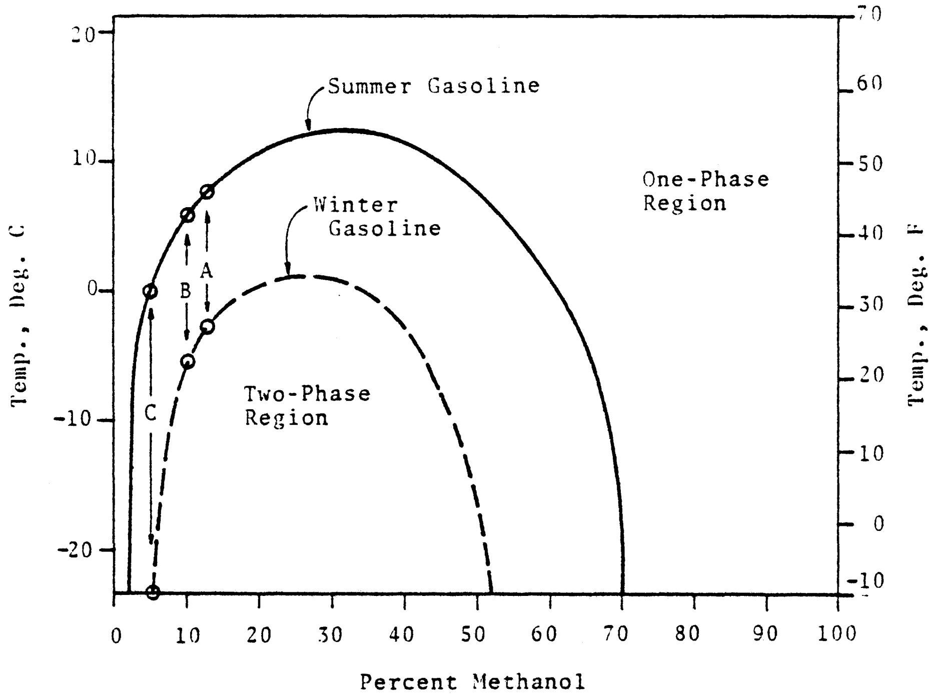

Figure 5. Separation of methanol in gasoline as a function of temperature. [After Reed et al.(9)]

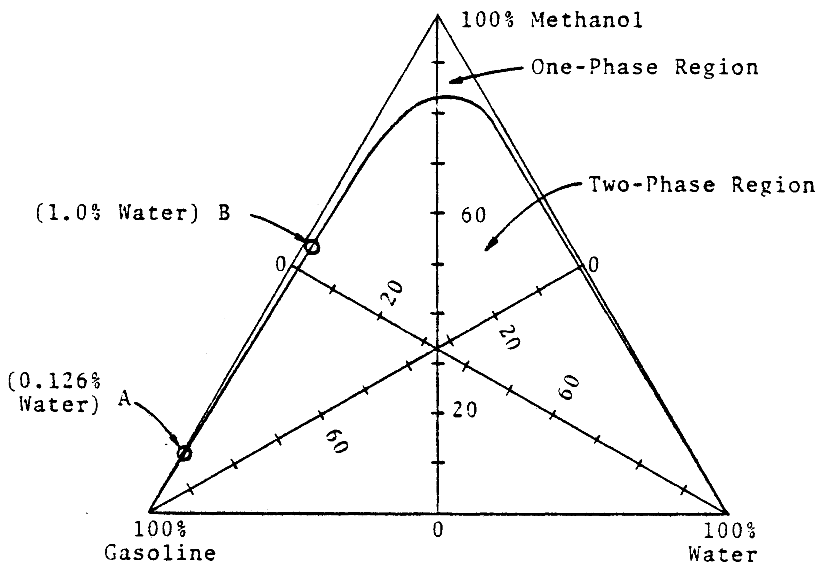

Figure 6. Equilibrium phase diagram for system: Methanol, water, and gasoline at 76°F. [After API.(10)]

of the storage containers. A dark brown sludge, predominately methanol, was noted in the bottom of the storage tank when the blend was stored for 4 to 6 weeks. A qualitative analysis of the sludge suggested a composition of primarily methanol; traces of water, which probably formed as the fuel evaporated and then condensed within the storage tank; and dissolved and suspended materials removed from the inner lining of the storage tanks because of the tremendous dissolving action of methanol. The methanol in the sludge would not blend with gasoline even at room temperature.

The blending pump was another source of trouble in handling the blends. The commercial fuel distributor who supplied the blending pump indicated that the methanol would probably react with the rubber seals in the pump and cause it to leak and, since methanol does not lubricate as well as gasoline, the idling gear of the pump would probably freeze on the shaft.* The pump did leak periodically throughout the 18 months of the field test and the exact cause of the leaking could not be determined. Replacing the pressure relief valves usually stopped the leaking temporarily. The filters on the pump had to be replaced about every 3 months because of the heavy concentration of sludge being removed from the storage tanks.

The data indicate that of the 1,000 gallons of methanol purchased for the tests, 732 gallons were burned as a blend, 38 gallons were discarded as sludge, 8 gallons were used in laboratory tests, 162 gallons remained in the storage tanks as methanol and sludge, and 60 gallons were unaccounted for and were believed to be lost through evaporation or leakage from the blending pump.

Monitoring the Concentration of Methanol

Since the miscibility of methanol in gasoline is a function of the hydrocarbon makeup of the gasoline, the temperature, and the concentration of water in the methanol it was necessary to implement a procedure in the laboratory that would permit a determination of the percentage of methanol contained in samples of fuel obtained periodically from the blending pump and the storage tank. The laboratory procedure, adapted from Ritchie and Kulawic,[11] involved using an infrared spectrophotometer to

*Personal communication from R. J. Hammer, April 1975.

compare samples of blends taken from the fueling area with standards prepared to have predetermined concentrations of methanol. By analyzing samples periodically, it was possible to monitor the performance of the blending pump and to detect separation in the storage tank.

Two-gallon samples obtained from the blending pump averaged 15.5% methanol and usually ranged from 15% to 16%. However, if samples of only about 1 pint were taken from the nozzle, methanol concentrations of 9% to 20% were found, which indicated the importance of taking the larger size sample.

The concentration of methanol in the gasoline in the storage tank was usually uniform above the sludge level, except when samples were taken immediately following the mixing operation; at that time a 1% to 2% variability between samples was common. Samples taken from the storage tank immediately after the addition of fuel, periodically during a 4-to 6-week storage period, and prior to adding more fuel indicated that the concentration of methanol did not change more than 1% to 2% during the 4-to 6 weeks required to use a particular batch of the blend. The sludge bottom was probably formed when some methanol separated either initially, because more was added than could be stored as a blend for the particular temperature conditions, or during the 4- to 6-week period due to changes in temperature or to evaporation and condensation. Occasionally there was 1% to 2% less methanol in the blend than was anticipated based on the quantities of methanol and gasoline added to the storage tank, but never was there a higher concentration of methanol in the gasoline above the sludge line than was anticipated.

The concentrations of methanol in the gasoline used by the test vehicles as presented at the top of Figure 1 of the report were based on periodic analyses of fuel samples. Without implementing a procedure for determining the concentration of methanol in the gasoline, it would have been impossible to know precisely what blends the vehicles used.

Implications of Experience

The experience gained from the field investigation strongly suggests that before methanol could be added to the fuel storage system operated by the Virginia Department of Highways and Transportation, the water and sludge would have to be removed from the storage tanks and the gaskets, seals, and other parts of the pumps which react with methanol would have to be replaced. The deliveries of methanol would have to be coordinated with the gasoline deliveries and the concentration of methanol would have to be determined periodically to ensure that the desired quantity of methanol in the fuel was maintained. This type operation would probably never be practical, except in an extreme situation such as one in which gasoline was being rationed.

Another approach would be to install an additional storage tank and a blending pump at each fueling area and blend the methanol and gasoline at the pump. The cost of implementing this procedure would be extremely high in light of the little gasoline that could be saved in operating on a blend containing approximately 10% methanol.

The third, and probably the most practical way, to substitute methanol for gasoline, and the way that was not investigated in this study program, would be to retrofit each vehicle with a second fuel tank and blend the fuel at the carburetor. With this procedure the carburetor could be adjusted to provide the most cost-effective blend. Starting the engine on gasoline and generally operating it on methanol would probably be desirable to achieve the greatest reduction in gasoline consumption with a minimum of modification to the vehicles. As with any of the alternatives, the vehicles and pumps would have to be retrofitted with parts that would not react with methanol. Any further research should be directed to the modification of vehicles for operation on blends with high concentrations of methanol or on straight methanol. It appears that the benefits don't and probably never will justify the costs associated with handling, storing, and dispensing gasoline containing approximately 5% to 15% methanol. However, the development of an economical additive that would prevent the separation of methanol from gasoline should eliminate the handling and storage problems and many of the problems in vehicle operation reported here.

Summary of Current Research on Alcohol Fuels

The third principal purpose of the investigation of alcohol fuels was to keep abreast of current research so as to establish a capability to conduct further research or to implement the use of alcohol as fuel should it become a feasible substitute for gasoline. The considerable amount of literature collected for the study shows that there is still considerable controversy as to the feasibility of substituting alcohol for gasoline. All of the literature deals with methanol (CH_3OH), which can be produced from almost any organic material, trash, wastes, etc.; and ethanol (C_2H_5OH), which is usually produced from grain. The economics of alcohol production seem to favor the use of methanol,[6] whereas the problems associated with handling and storing alcohol-gasoline blends and of operating vehicles on them seem to favor the use of ethanol. Methanol costs the same as lead-free gasoline whereas ethanol costs about twice as much. Ethanol has a Btu content which is 68% that of gasoline whereas the Btu content of methanol is only 51% that of gasoline. Also ethanol has a theoretical air-fuel ratio of 9.0, which is closer to the 15.1 of gasoline than is the 6.5 of methanol.[10]

Should private industry construct the plants to produce alcohol at a cost-effective price, the operation of vehicles on pure alcohol or high percentages of alcohol mixed with gasoline could prove to be desirable. However, vehicles must be properly retrofitted to operate on alcohol and, to provide desirable versatility, the vehicles should be capable of operating on both alcohol and gasoline. The study experience supports the suggestion from the literature that the operation of vehicles on small quantities of methanol blended with gasoline is not economically feasible at this time. Much of the currently available literature on the use of alcohol as motor vehicle fuel is summarized below.

Performance of Methanol-Gasoline Blends

1. Dr. Robert H. Lindquist of the Standard Oil Company has reported that tests conducted with six vehicles operating on a blend of 10% methanol produced the following results:[2]

    a) Fuel economy decreased 3% on the average with a range of 1% - 6%;

    b) driveability problems such as hesitation and poor starting were reported;

    c) exhaust emissions did not change;

    d) three vehicles stalled on the highway; and

    e) methanol separated from the gasoline in the presence of 0.1% water.

2. R. R. Cecil of Exxon reports that "the addition of only 2% methanol to gasoline can raise the reid vapor pressure of some gasolines by 3% and to a value which will not meet many legal codes."[12]

3. T. B. Reed has indicated that "up to 15% methanol can be added to commercial gasoline in cars now in use without it being necessary to modify the engines."[3]

4. "German auto engineers have run into no major problems while burning a 15% methanol mixture in a fleet of 45 Volkswagen vehicles."(13) "It was necessary to replace carburetor floats, idle fuel solenoids, fuel filters, and fuel lines made of polyamid 6."(14)

5. "Racing experiences with methanol fuel blends indicate several types of practical operational problems with water solubility, plastics-solvent action, metal corrosion, galvanic effects, low air-fuel ratios, low Btu content, and high latent heat."(15)

6. N. D. Brinkman of General Motors reports that "adding alcohol to gasoline without carburetor modifications decreased carbon monoxide emissions, volume based fuel economy, driveability, and performance."(8)

7. "Fleet tests of 30 Volvo cars operating on 16% methanol and 4% isobutanol [added to reduce separation of blend] in gasoline have resulted in fuel consumption which is similar to that of pure gasoline. Lubrication problems resulted in damaged cams and lifters but the problem was solved by using correct additives in the oil."*

Performance of Straight Methanol

1. E. F. Lindsley reports that the tests conducted by Texas A & M University indicate cold start problems can be overcome by starting a vehicle on gasoline and converting to pure methanol after the engine warms up.(16)

2. The University of Santa Clara reports that two vehicles have operated on pure methanol for about 5 years with no significant problems. The fuel economy in miles/Btu is the same for pure methanol as for gasoline.(17)

Availability of Methanol

1. The following quotes from the minutes of the hearings on methanol during the 94th Congress reflect the controversy

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*Personal communication from Dag Vendil to T. B. Reed, February 1976.

over the relative merits of methanol production. "The manufacture of methanol from organic waste or coal has not begun because of economic constraints." "The cost to produce methanol via in-situ coal gasification is expected to be low enough to be competitive with gasoline at the pump." "The production of methanol from coal is an energy inefficient process, having a conversion efficiency of 41%-46%."[18]

2. The American Petroleum Institute has indicated that alcohol, particularly methanol derived from coal, will probably power cars and trucks within the next ten years, if production costs can be reduced.[19]

3. The U. S. produces 1.2 billion gallons of methanol a year entirely from natural gas. It is used mainly in making glue for plywood and in the manufacture of plastics, synthetic fibers, and drugs.[20]

Performance and Availability of Ethanol-Gasoline Blends

1. "In foreign countries where gasoline is in short supply, blends of from 5% to 25% ethanol have been commercially used in motor vehicles for several years."[21]

2. "Generally speaking, no insurmountable problems have been experienced in Brazil, where ethanol has been used as a gasoline component up to 25% by volume since 1930. However, sporadic problems associated with poor driveability, water separation, vapor lock, increased intake system deposits, carburetor tank corrosion, and increase in gum formation are experienced by motorists."[22]

3. "The Senate recently approved legislation funding alcohol fuel research and guaranteeing loans for four pilot distillery projects."[23]

4. "The two-million mile 'Gasohol' [10% ethanol and 90% unleaded gasoline] road tests conducted in Nebraska indicate that the addition of 10% ethanol to gasoline increases octane number and volume and decreases fuel consumption by 6.7% with no problems. However, the principal investigator, Dr. William A. Sheller, indicates that grain supplies are limited and therefore the use of 10% ethanol will be limited to the grain producing areas of the country."[24]

DISCUSSION

In the study four 1973 and 1974 model vehicles were operated over a period of 18 months on unleaded gasoline containing an average of 10.7% methanol. On the average, 1.6 gallons of methanol were required to replace 1 gallon of gasoline. The Virginia Department of Highways and Transportation currently consumes 8.4 million gallons of gasoline per year; therefore, large-scale duplication of the test program would require the purchase of 0.94 million gallons of methanol to achieve a 0.57 million gallon reduction in gasoline consumption. Neglecting the overhead costs associated with implementing the use of blends, the break-even price of methanol would be $0.25 per gallon based on the current cost of gasoline of $0.40 per gallon. The overhead cost associated with storing and dispensing the blend and retrofitting vehicles for satisfactory operation on methanol-gasoline blends would make the break-even cost of methanol much less than $0.25 per gallon.

One would expect a vehicle to operate most efficiently if it operated on the same fuel at all times. Therefore, adjusting the percentage methanol in the blend would probably not be desirable or practical on a large scale. Accordingly, one could not expect to operate on more than about 6% methanol on a year-round basis because of the tendency of methanol to separate from the gasoline at higher concentrations. A more realistic approach to substituting methanol for gasoline might be to retrofit vehicles for operation on pure methanol. Most of the handling and storage problems associated with blends would be eliminated. The disadvantage would be that operation on gasoline would probably not be possible and methanol pumps would, therefore, have to be provided throughout the state to ensure that all state vehicles would have ready access to fuel.

The technical problems associated with operating a motor vehicle on alcohol are not insurmountable. The fundamental problem to overcome lies in obtaining supplies of methanol. Since blends of ethanol and gasoline have been used in other countries for many years, the main problem of implementing the use of ethanol-gasoline blends here would also be one of supply. Once alcohol is commercially available in large supply at an economical price, whether it be methanol or ethanol, there should not be much of a problem in determining how best to use it.

CONCLUSIONS

The following conclusions are based on the 18-month field test involving eight vehicles, half of them operating on an average of 10.7% methanol blended with gasoline and the other half on unleaded gasoline.

1. The vehicles operating on the blends averaged 4.0% fewer miles per gallon than did those using gasoline.

2. The fuel mileage obtained with the vehicles using the blends agrees well with results reported by several other testing organizations.

3. Since a gallon of methanol has 51% of the energy of a gallon of gasoline, the vehicles operating on the blend should have obtained 5.2% fewer miles per gallon, if the blend was utilized at the same efficiency as the gasoline. Therefore, from a miles/Btu standpoint, the vehicles operating on the blend were 1.3% more efficient.

4. Exhaust emissions data supported the conclusion by other researchers that emissions are more dependent on carburetor adjustments than on the percentage of methanol in the fuel.

5. Driveability was impaired enough in two of the five vehicles using the blended fuel to warrant carburetor modifications to adjust the air-fuel mixture that had been made too lean by the addition of the methanol.

6. Because methanol and gasoline are not completely miscible at all temperatures and moisture conditions, a considerable effort was required to properly store and dispense the desired blends.

7. The fuel data indicate that 1.6 gallons of methanol were required to replace 1.0 gallon of gasoline. Therefore, for equal economy the price of methanol would have to be $0.25 per gallon when gasoline costs $0.40 per gallon. However, when the overhead cost associated with storing and dispensing the blend and retrofitting vehicles for operation on methanol-gasoline blends is taken into account, the purchase price of methanol would have to be much less than $0.25 per gallon to be competitive with gasoline which costs $0.40 per gallon.

8. The field investigation proved extremely valuable in providing the practical knowledge necessary to implement the use of methanol-gasoline blends, should there be a change in the price and supply of methanol with respect to gasoline that would justify such action.

9. Retrofitting vehicles for operation on blends with high concentrations of methanol or on pure methanol could conceivably be more practical than the operation of vehicles on blends containing small percentages of methanol, but field experience is needed to confirm or disprove this speculation.

10. Methanol currently costs about the same or more than lead-free gasoline. However, supplies are limited and are predominately petroleum derived, and from an economic and supply standpoint, the use of methanol-gasoline blends in Department vehicles would not be justified at this time.

RECOMMENDATIONS

1. The Virginia Department of Highways and Transportation should not implement the use of methanol-gasoline blends at this time, because on the bases of economics and supply it is not justified.

2. The Department should keep abreast of research related to the use of alcohol as a motor vehicle fuel.

3. The Department should consider retrofitting several vehicles for operation on pure methanol to gain some additional practical experience.

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