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MASTER

ETHANOL/GASOLINE BLENDS AS AUTOMOTIVE FUELS

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ABSTRACT

An experimental study of gasoline and 10% ethanol/90% gasoline blends was made using five late-model vehicles operated on a climate-controlled chassis dynamometer. Data were obtained to permit comparisons of fuel economy, emissions, and other significant operational characteristics observed in tests with the two fuels.

Volumetric fuel economy was shown to be slightly decreased while energy economy was slightly increased using the ethanol/gasoline blend.

Compared with the results using base gasoline, the use of the ethanol/gasoline blend had no adverse effect upon regulated emissions at test temperatures within the range 20° to 75° F; at 100° F there were minor increases in emissions using the ethanol/gasoline blends.

Addition of ethanol at 10% concentration generally either had no effect or only slight effect on unburned hydrocarbon; an exception was noted for 100° F at which temperature unburned hydrocarbon from the blend was increased significantly over that found with the base fuel.

Road octane quality of the ethanol/gasoline blend was increased by about 3.5 numbers over the base fuel.

INTRODUCTION

Ethanol has been used in internal combustion engines for many years both in pure form and mixed with gasoline. Both beneficial and detrimental characteristics of ethanol as motor fuel have long been noted and widely recognized. The present situation is complex, however, and there are many factors that should be considered before ethanol/gasoline blends are widely marketed in the United States. Some of the questions that should be answered before such a move is made are: (1) What effect will the use of ethanol have on exhaust emissions of current and future production vehicles which must meet governmentally-improved emissions standards?, (2) What effect will the use of ethanol have on meeting federally-mandated fuel economy standards of present and future vehicles?, (3) What effect will ethanol have on life expectancy of current and future emission control systems which are currently mandated to control emissions for 50,000 miles?, and finally, (4) What are the economics of ethanol compared with other attractive alternative fuel options?

In an effort to provide information concerning some of the above questions, the Bartlesville (Okla.) Energy Technology Center, in cooperation with the Division of Transportation Energy Conservation of the Department of Energy, undertook a program of research to investigate the effect of

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using a 10% ethanol/90% gasoline fuel mixture on vehicle emissions and fuel economy using late-model vehicles with current and advanced emission control systems.

EQUIPMENT AND PROCEDURES

Emission and fuel economy data were generated on a chassis dynamometer in an enclosed facility capable of maintaining ambient temperature from 20° to 100° F. The chassis dynamometer, constant volume sampling (CVS) system, and emission measuring equipment are those specified in the federal emission test procedure [1]*. In addition to "bag measurements" as specified by the federal test procedure (FTP), the regulated emissions plus carbon dioxide (CO_2) and exhaust flow and dilution air flow were measured continuously. The real time measurement provided an internal check of the bag measurements and aided in detailed modal analysis during and subsequent to the test.

In addition to the regulated emissions measurements, aldehyde and alcohol content of the exhaust were also measured. Aldehydes were measured by the 3-methylbenzothiazolone hydrazone (MBTH) method [2]. A procedure utilizing gas chromatography for determining unburned ethanol was developed as part of the overall project and is described in a separate publication [3]. Hydrocarbon character of the exhaust was determined by gas chromatography [4].

The five vehicles used in the test are described in table 1. Two of the vehicles utilized 3-way catalyst systems for emission control with closed loop feedback from exhaust oxygen sensors for air-fuel (A/F) mixture control. The vehicles had accumulated 3,000 to 10,000 miles using unleaded gasolines prior to tests conducted with the alcohol-blended fuels.

The vehicle's engines were adjusted to manufacturers' specifications at the start of the test and not readjusted during the program.

Emissions and fuel economy were measured at ambient temperatures of 20°, 45°, 75°, and 100° F to determine influence of temperature on exhaust characteristics. At each temperature condition, emissions were measured using a base gasoline and a blend of 90 vol-pct gasoline base/10 vol-pct anhydrous ethanol. In the following discussion the latter fuel will be referred to as "ethanol blend". Analyses of the test fuels are reported in table 2. Triplicate tests were conducted at each temperature/ test fuel condition and results averaged to insure data reliability. Exhaust hydrocarbon (HC) composition was determined in only two of the triplicate tests (for four of the vehicles).

The evaporative emissions were not determined on the vehicle tests and the vehicles were not subjected to a "heat build" soak period prior to emissions testing. The vehicles were conditioned by operation through an LA-4 cycle with the test fuel in the vehicle's fuel tank and allowed to

*Numbers in brackets designate References at the end of paper.

soak at the specified test temperature for 12 to 18 hours prior to emissions testing. Ambient temperature was maintained in the test facility within ±2° F at 45°, 75°, and 100° F. While at the 20° F test condition, the tests were started at about 18° F with the temperature rising to about 30° F during the highway fuel economy portion of the test cycle.

EMISSIONS/FUEL ECONOMY.

A comparison of exhaust emission data between the base gasoline and the ethanol blend at 75° F ambient temperature is presented in Fig. 1. The results indicate reductions in all regulated emissions using the ethanol blend compared to gasoline. Carbon monoxide (CO) emissions were reduced approximately 25%, unburned hydrocarbons approximately 14%, and oxides of nitrogen (NO_X) were decreased approximately 6% by the use of the ethanol blend compared to the base fuel. However, aldehyde emissions were increased by approximately 25% Fuel economy results (Fig. 2) show that at 75° F, base gasoline attained slightly greater volumetric fuel economy (mpg), and the ethanol blend attained slightly greater fuel energy economy (mi/10^5 Btu). However, the differences in fuel economy between the two fuels are less than 2.5% expressed either on a volumetric or an energy basis. Therefore, a much larger sampling of vehicles is necessary before a statistically meaningful number can be attributed to the fuel economy effect of large-scale usage of ethanol blended with gasoline.

Temperature Effect

Alcohols, when added to gasoline, have been shown by other researchers to sometimes markedly affect the fuel's vapor pressure and distillation characteristics [5] which may, depending upon ambient temperatures, affect engine operation. Some researchers have also suggested significant fuel economy differences exist between using gasoline and gasoline/alcohol mixtures at ambient temperatures lower than the federal test specifications [6]. Therefore, in addition to testing the vehicles at the federal specified temperature of 68° to 86° F, the vehicles were also tested for exhaust emissions and fuel economy at 20°, 45°, and 100° F.

Emissions data show minimum CO emissions (Fig. 3) occur at 75° F using both fuels; however, the ethanol blend generally produced less CO than the base gasoline. For example, at the 20°, 45°, and 75° F test conditions, the use of the ethanol blend produced about 20% less CO than the base fuel; however, at the 100° F condition, CO emissions were essentially equivalent for both fuels.

Modal analyses suggest that a large part of the CO differences between the two fuels occur during cold engine operation in which A/F mixture is generally rich. However, at the 100° F condition the "hot start" CO emissions are higher with the ethanol blend compared to gasoline.

Hydrocarbon emissions trends (Fig. 4) are very similiar to CO emissions described above in that hydrocarbons are essentially doubled by operation at 20° F compared to 75° F using either fuel. Between fuels, however, the ethanol blend showed HC reduced approximately 10% at 20°, 45°, and 75° F; at the 100° F condition, hydrocarbons were increased about 15% with the use of the ethanol blend as compared to gasoline.

Oxides of nitrogen emissions (Fig. 5) were only slightly affected by temperature. An NO_X reduction of about 7 percent was apparent at the 20° and 45° F condition by the use of the ethanol blend compared to the base gasoline; however, at 75° F the difference is essentially nil, and at 100° F the use of ethanol blend produced about 5% more NO_X than using the base fuel.

Exhaust aldehydes (Fig. 6) were also only moderately affected by ambient temperature. The use of the ethanol blend fuel produced approximately 25% more aldehydes than the base fuel at all temperatures except at 45° F where the emissions levels from both fuels are similar.

The unburned ethanol level (Fig. 7) was shown to be dependent upon ambient temperature with the minimum levels occurring at 75° F. The amount of ethanol in the exhaust using the ethanol blend fuel ranged from 2.5 to 3% of the amount of total unburned hydrocarbons in the exhaust at each test temperature. Essentially no ethanol was detected in the exhaust of the vehicles operating on the base fuel.

Fuel economy was affected by ambient temperature using both fuels with approximately 2 miles/gallon improved fuel economy attained by operation at 100° F compared to 20° F. In comparing fuels, volumetric fuel economy (Fig. 8) for both urban and highway portions of the test cycle was shown to be decreased using the ethanol blend at all temperature conditions. A comparison of the difference in composite fuel economy (weighted urban/highway) between the base and ethanol blend fuel is shown in Fig. 9. The data show the volumetric fuel economy of the ethanol blend fuel to be about 2.5% lower than the base fuel which closely corresponds to the 3.4% lower energy content of the ethanol blend fuel.

Advanced Emission Control Systems

Some advanced emission control systems utilize exhaust oxygen sensors to feed back a signal to the fuel induction system for precise A/F mixture control. The system's primary function is to maintain the A/F ratio near stoichiometric conditions, which is necessary for 3-way catalyst operation for effective control of CO, HC, and NO_X. A side bonus from the exhaust feedback systems is the potential of the hardware to maintain the same stoichiometric A/F ratio while using either straight gasoline or alcohol/gasoline blends.

Two vehicles in the test fleet utilized 3-way catalysts with closed loop A/F control systems. Test data from these systems and comparable data from systems utilizing straight oxidation catalyst suggest the following:

The influence of temperature (Figs. 10 and 11) in CO and HC emissions shows similiar effects and trends for 3-way and for oxidation catalyst; these effects and trends are essentially alike for the base gasoline and ethanol blend.

Carbon monoxide emissions are primarily a function of A/F; therefore, any emission control system that allows fuel rich operation is expected to produce significant CO emissions, and fuels that effectively "lean" A/F mixtures condition are expected to reduce CO emissions. The majority of CO and HC emissions from the 3-way catalyst systems is produced during cold start (rich A/F) operation in which the exhaust oxygen sensor signal is overridden. As a result, lower CO and HC emissions can be expected from ethanol blends compared to gasoline using both 3-way and oxidation catalyst systems provided a significant portion of the emissions is produced during cold start (rich A/F) operation. Unburned HC emissions are significantly lower from the 3-way catalyst systems at all temperatures and both fuels compared to the oxidation catalyst systems.

Oxides of nitrogen emissions from the vehicles equipped with 3-way catalysts were significantly reduced compared to the other systems, using both test fuels and at all temperatures (Fig. 12). Oxides of nitrogen emissions were essentially unaffected by the use of the ethanol blend in the vehicles equipped with 3-way catalyst systems.

Exhaust aldehydes were found to be lower (by a factor of approximately 4) from the vehicles with the 3-way catalyst systems compared to the vehicles with oxidation catalyst systems (Fig. 13) at all temperatures and with both test fuels. However, aldehydes were generally increased by use of the ethanol blend fuel compared to the base gasoline in both types of catalyst systems.

In using the ethanol blend fuel, the 3-way catalyst equipped vehicles produced about one-half the amount of unburned ethanol in the exhaust as vehicles equipped with oxidation catalysts.

Hydrocarbon Characterization

Detailed exhaust hydrocarbon analyses were conducted to determine the effect of using the ethanol blend fuel on the exhaust hydrocarbon composition. These data were obtained for four of the test vehicles (two vehicles with oxidation catalyst and two vehicles with 3-way catalyst) at 20°, 45°, 75°, and 100° F ambient temperatures using both fuels.

Hydrocarbon compositional data are presented by classes of hydrocarbons calculated on a mass basis (gm/mile) considering the weighted contribution of the three phases of the test cycle. The data are presented in Fig. 14 through 17. Fig. 14 presents the total paraffins, aromatics, and olefins at the various temperatures. The results suggest the ethanol blend fuel produces either the same as, or slightly less, total paraffins, aromatics, and olefins than the base fuel at all temperatures using both catalyst systems--a single exception being at 100° F in which the 3-way catalyst system produced more paraffins using the ethanol blend fuel than the base fuel. Closer examination of the exhaust paraffins at 100° F test temperature with the 3-way catalyst system (Fig. 15) suggests also that the amount of normal, iso, and C_{4+} paraffins are all increased using the ethanol blend fuel compared to base fuel. At all other test conditions the ethanol blend fuel produced the same or lower levels of paraffins than did the base fuel.

The amount of benzene as well as C_{7+} aromatics (Fig. 16) in the exhaust of the oxidation catalyst vehicles was reduced by the use of the ethanol blend compared to the base fuel; however, using the 3-way catalyst systems, the exhaust aromatics were essentially unaffected by the ethanol blend fuel. The amount of acetylene (Fig. 16) in the exhaust is essentially unaffected by use of the ethanol blend fuel.

Examination of the olefin classes in the exhaust (figure 17) suggests reductions of ethylene and alkenes due to the use of the ethanol blend fuel compared to the base fuel in the oxidation-catalyst-equipped vehicles at all test temperatures except 100° F. The internal alkenes and diolefins in the exhaust are unaffected by the ethanol blend fuel at all temperatures using both catalyst systems.

The hydrocarbon characterization results show that (a) ambient test temperature and type of emission control system affects the hydrocarbon distribution to a much greater extent than does using the ethanol blend fuel compared to the base gasoline, and (b) the use of the ethanol blend generally had either no effect on or reduced the exhaust HC components except at the higher temperature test condition.

ROAD OCTANE RESPONSE

The road octane rating of ethanol/gasoline mixtures was determined on four of the test vehicles. Octane determinations were not conducted on the Volvo due to inability to change fuels quickly while using the fuel-injection system. Road octane determinations were conducted using three base fuels of 81, 86, and 91 research octane number (RON), each with 0, 5, and 10% anhydrous ethanol added. A modified Uniontown road octane technique was used, except the tests were conducted on a chassis dynamometer. Relatively constant ambient temperature conditions were attained by operation only during morning hours. A single test consisted of comparing the reference fuels and all test fuels in one vehicle without interruptions. Triplicate tests were conducted for each vehicle/fuel combination.

The data (Fig. 18) show that addition of 10% ethanol increases the road octane value of an 81 RON base fuel by about 4.5 numbers and a 91 RON base fuel by about 3 octane numbers. The octane increase due to ethanol was found to be relatively linear within the range tested.

The average road octane blending value of ethanol ranged from 122 for the 81 RON fuel to 117 for the 91 RON base fuel.

SUMMARY

Vehicle tests were conducted to determine the effects on fuel economy and emissions in adding 10 vol-pct ethanol to a base gasoline. Comparative road octane values were also determined for the base fuel and blend. Results show that compared to the base gasoline the addition of ethanol at 10% concentration results in the following:

- Decreased volumetric fuel economy.
- Increased fuel energy economy.
- Reduced CO, HC, and NO_X emissions at 20°, 45°, and 75° F.
- Increased HC and NO_X emissions at 100° F.
- Aldehyde emissions increased by about 25% at 20°, 75°, and 100° F.
- Exhaust HC distribution not materially affected.
- Road octane quality of an 81 RON fuel increased by 4.5 numbers and a 91 RON fuel by 3 numbers.

BIBLIOGRAPHY

1. Environmental Protection Agency. New Motor Vehicles and New Motor Vehicle Engines. Federal Register, Part II, v. 37, No. 221, Nov. 15, 1972.

2. Coordinating Research Council Inc. Oxygenates in Automotive Exhaust Gas: Part I - Techniques for Determining Aldehydes by the MBTH Method. CRC, New York City, November 1967, 21 pp.

3. Raible, C. J. Chromatographic Method of Analysis for Methanol and Ethanol in Auto Exhaust. BETC/RI (in press).

4. Seizinger, D. E. High Resolution Gas Chromatographic Analysis of Auto Exhaust Gas. Perkin-Elmer Instrument News, v. 18, No. 1, October 1967, p. 1112.

5. Scheller, W. A. Tests on Unleaded Gasoline Containing 10% Ethanol - Nebraska GASOHOL. Pres. at the International Symposium on Alcohol Fuel Technology, Wolfsburg, Germany, Nov. 21-23, 1977, 5 pp.

6. Scheller, W. A. Gasohol Two Million Mile Road Test. Proceedings of the Nebraska Midwest Regional Gasohol Conference, Lincoln, Nebraska, Nov. 12, 1977, pp. 8-16.

TABLE 1. - Description of test vehicles

Year Make/Model	Engine, cu-in. displacement	Transmission	Type emission control
1975 Dodge Colt	98	Auto/3-speed	Air injection/EGR
1976 Chevrolet Impala	350	Auto/3-speed	Oxidation catalyst/EGR
1977 Pontiac Astre	151	Manual/5-speed	Oxidation catalyst/EGR
1977 Volvo 242	130	Auto/3-speed	3-way catalyst[1]
1978 Ford Pinto	140	Auto/3-speed	3-way catalyst/EGR[1]

[1] Systems include closed loop feedback for A/F control.

TABLE 2. - Fuel specifications

	Base fuel	Base fuel + 10 pct ethanol
FIA, analysis pct:		
Aromatic	28	-
Olefin	8	-
Saturates	64	-
Distillation, ASTM D86:		
IBP	90	90
Pct evaporated:		
5	111	108
10	124	118
20	151	135
30	184	148
40	210	162
50	233	217
60	256	244
70	282	272
80	312	301
90	347	338
95	480	373
EP	416	410
Specific gravity	0.746	0.751
Reid vapor pressure, psi	9.7	10.9

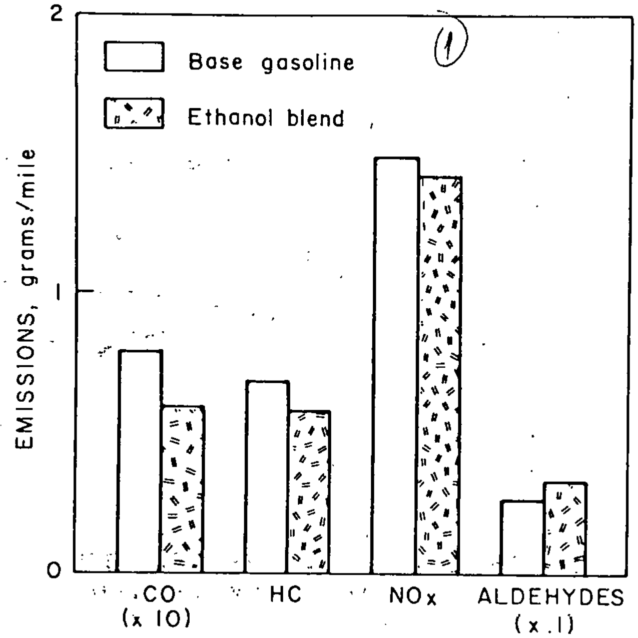

Fig. 1. - Influence of Fuels on Exhaust Emissions, 75°F

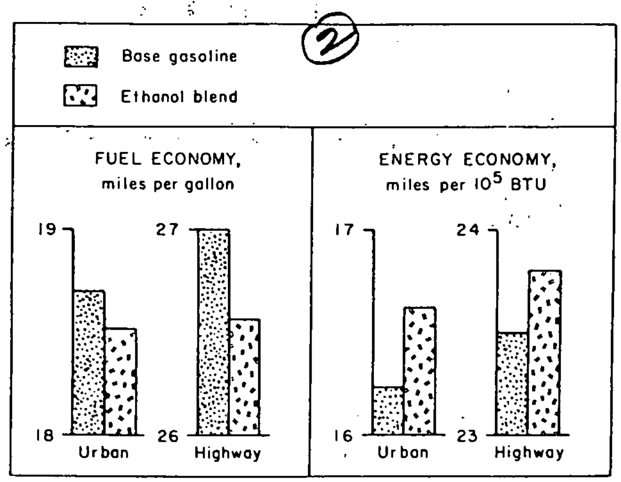

Fig. 2. - Influence of Fuels on Fuel Economy, 75°F

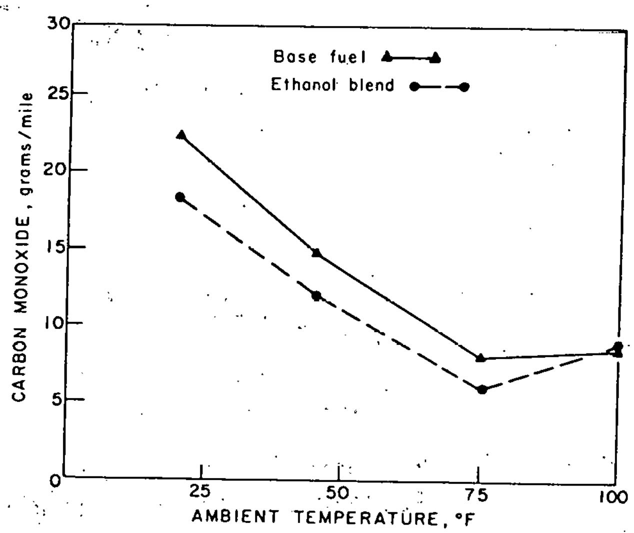

Fig. 3. - Influence of Ambient Temperature on CO Emissions

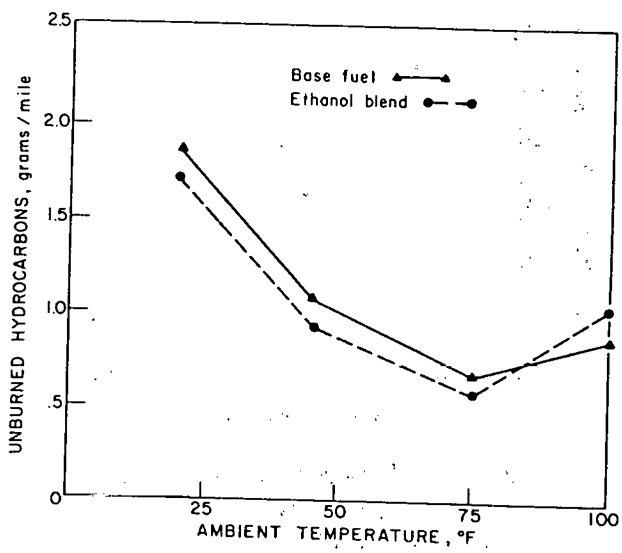

Fig. 4. - Influence of Ambient Temperature on HC Emissions

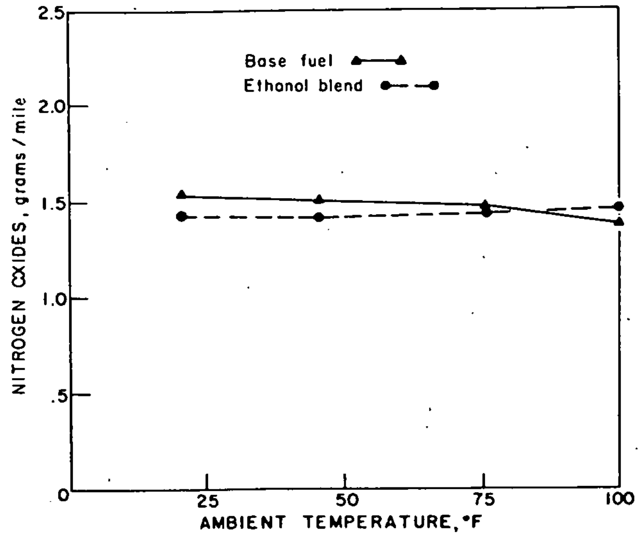

Fig. 5. - Influence of Ambient Temperature on NO_x Emissions

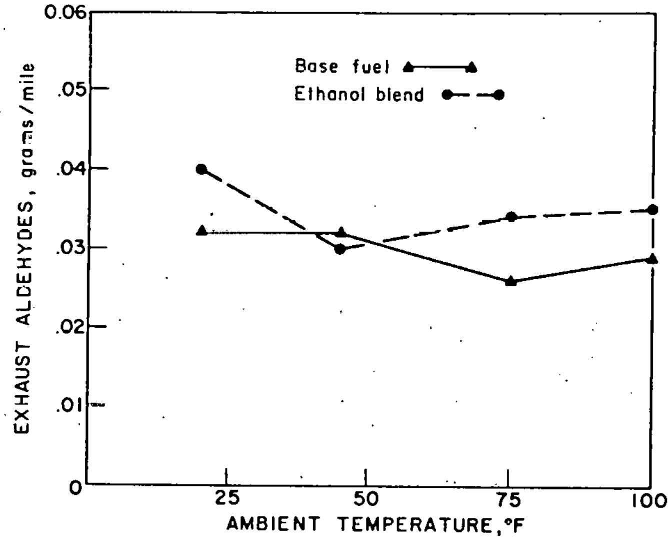

Fig. 6. - Influence of Ambient Temperature on Aldehyde Emissions

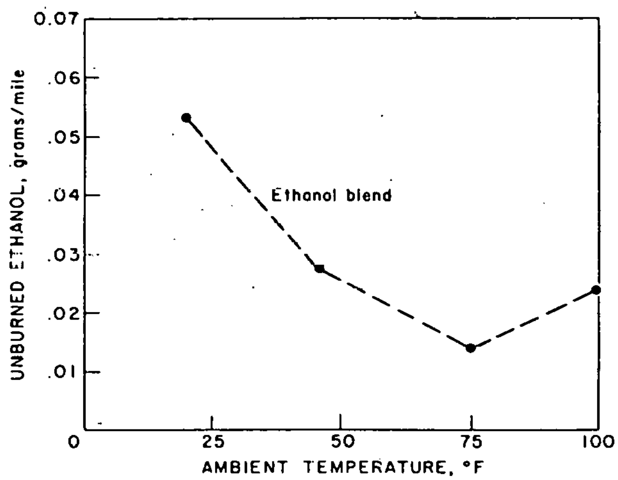

Fig. 7. - Influence of Ambient Temperature on Ethanol Emissions

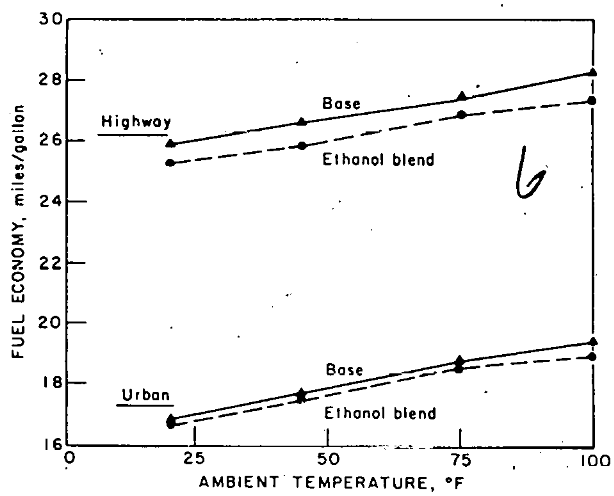

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Fig. 8. - Influence of Ambient Temperature on Fuel Economy

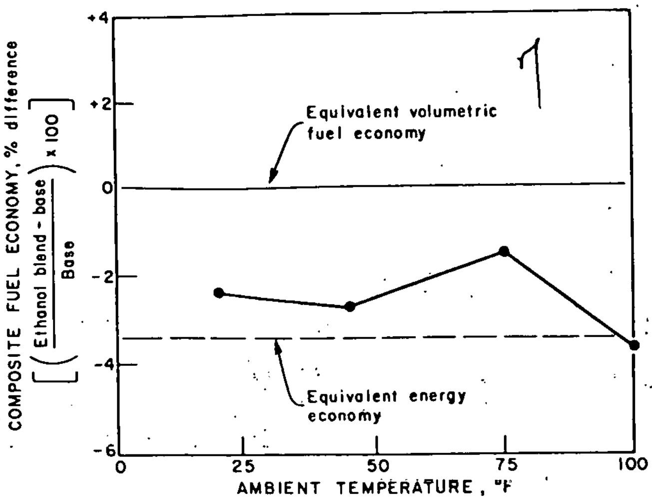

Fig. 9. - Influence of Fuel and Ambient Temperature on Fuel Economy

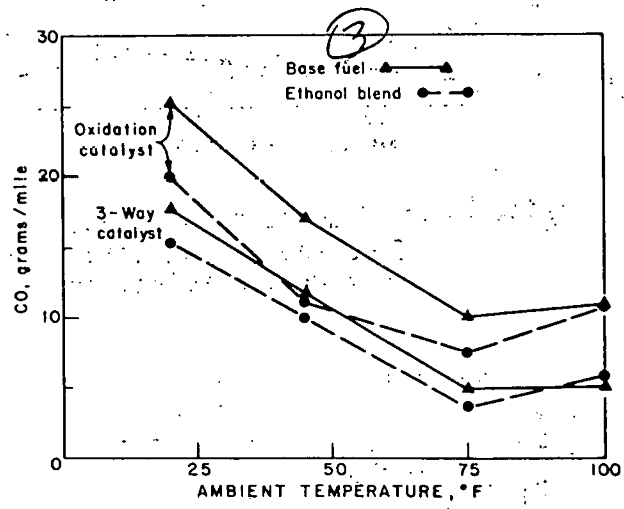

Fig. 10. - Influence of Ambient Temperature and Catalysts on CO Emissions

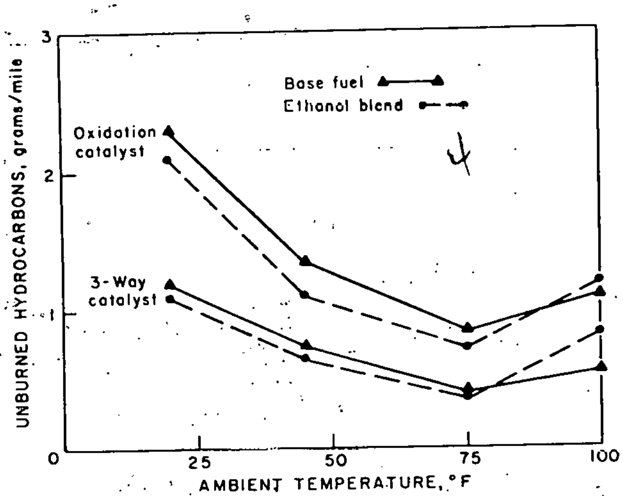

Fig. 11. - Influence of Ambient Temperature and Catalysts on HC Emissions

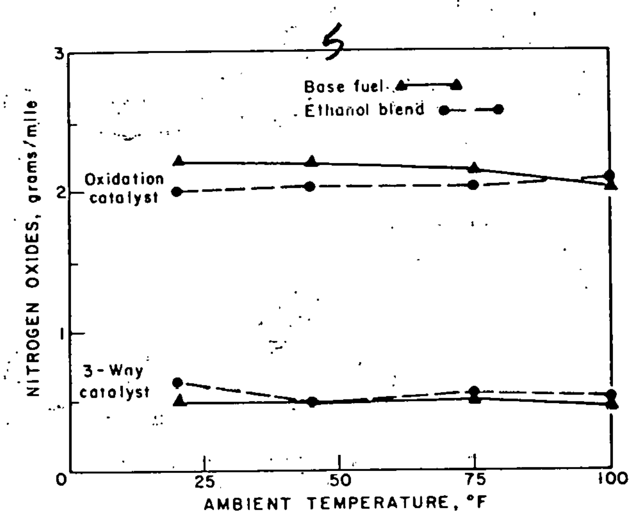

Fig. 12. - Influence of Ambient Temperature and Catalysts on NO_x Emissions

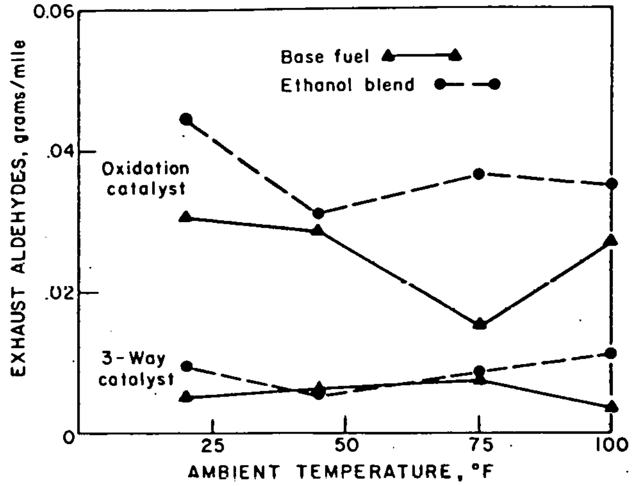

Fig. 13. - Influence of Ambient Temperature and Catalysts on Aldehyde Emissions

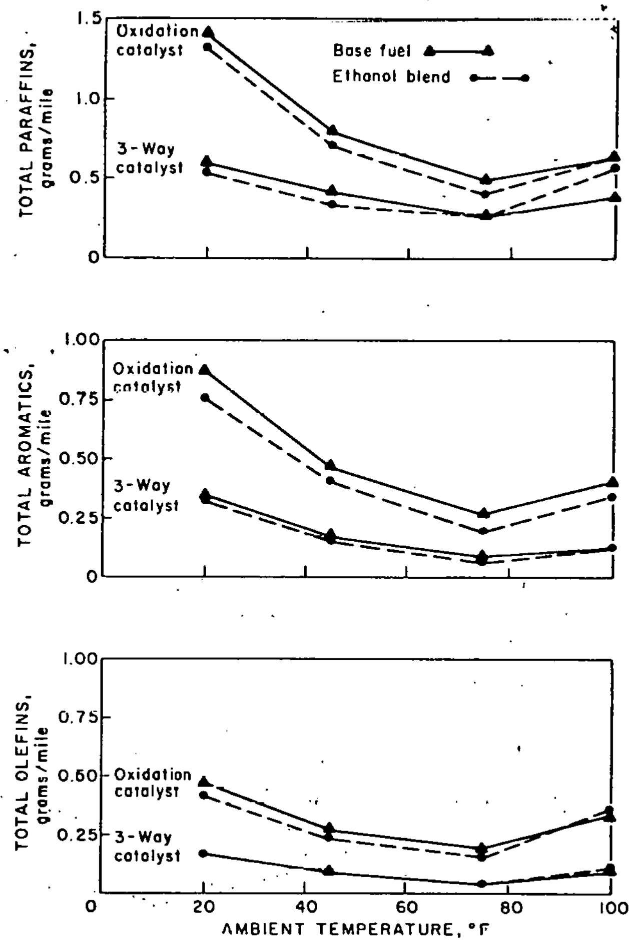

Fig. 14. - Influence of Ambient Temperature on HC Composition

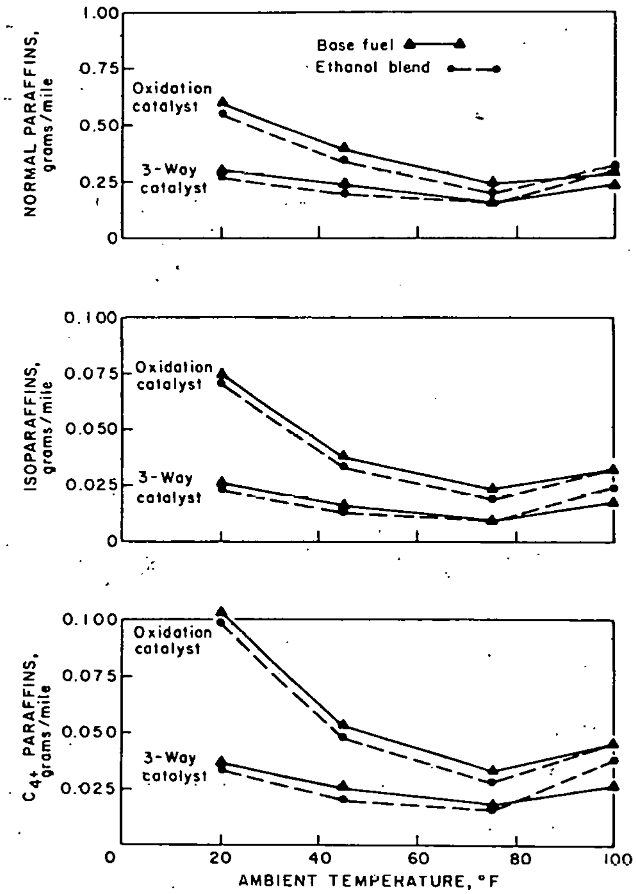

Fig. 15. - Influence of Ambient Temperature on Exhaust Paraffins

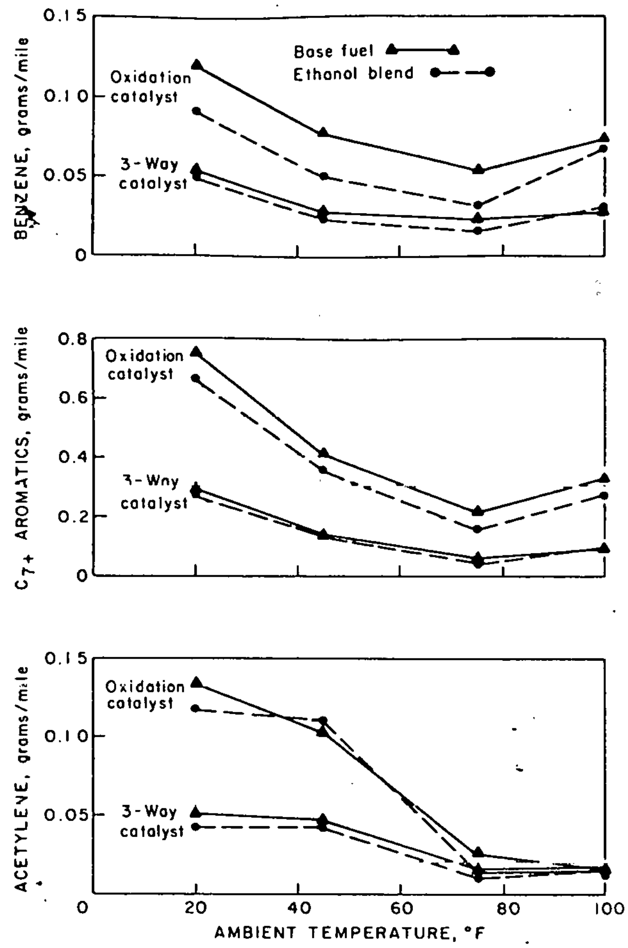

Fig. 16. - Influence of Ambient Temperature on Exhaust Aromatics and Acetylene

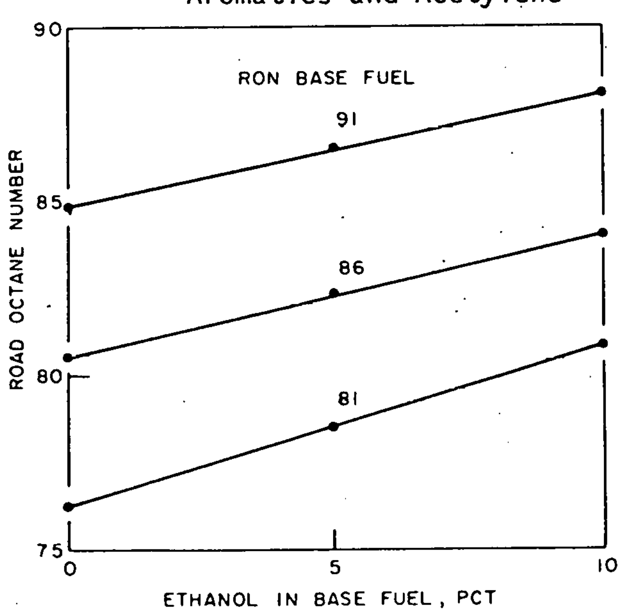

Fig. 18. - Influence of Ethanol on Road Octane

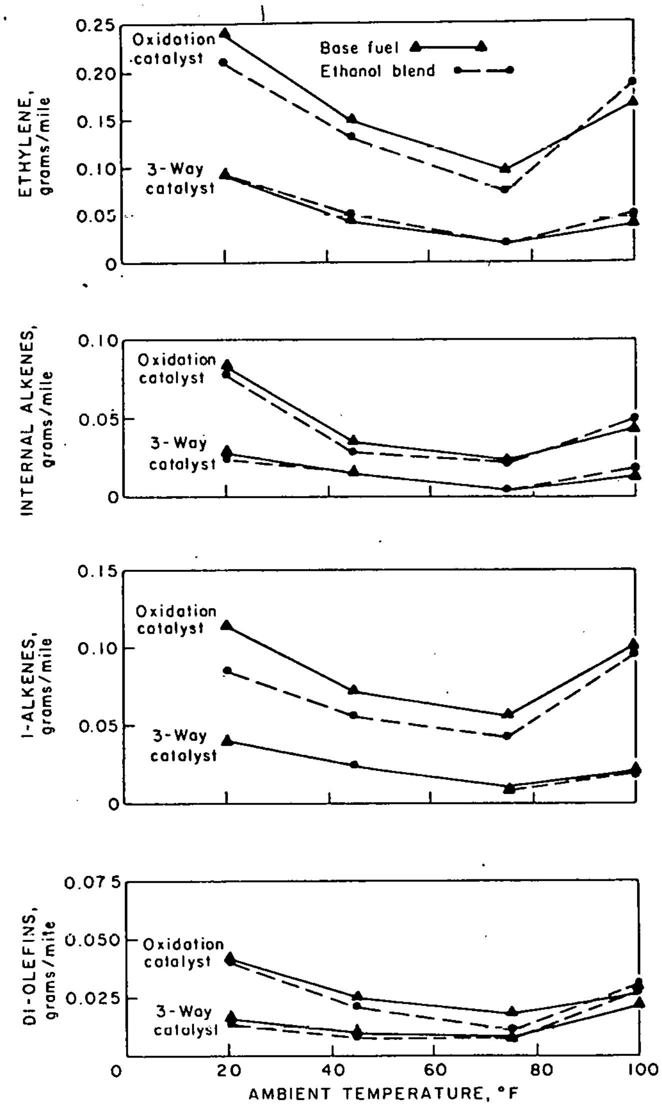

Fig. 17. - Influence of Ambient Temperature on Exhaust Olefins