METHANOL FUEL VEHICLE DEMONSTRATION: EXHAUST EMISSION TESTING

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New York State
Energy Research and Development Authority
Two Rockefeller Plaza • Albany, New York 12223-9998
(518) 465-6251 FAX: (518) 432-4630

An Energy Authority Report in Brief

Report: **Methanol Fuel Vehicle Demonstration: Exhaust Emission Testing, Report 93-10**

Project Manager: **Lawrence R. Hudson**

Contractor: **NYS Department of Environmental Conservation**

Background: This report describes the results of more than 300 emissions tests conducted by the NYS Department of Environmental Conservation (DEC) on four methanol Ford Crown Victorias over a four-year period. These vehicles were operated by the NYS Thruway Authority as part of its standard fleet. This project built on knowledge gained through earlier participation in Canada's Project MILE, projects using methanol in large engines, in which a similar approach was used for urban delivery trucks in Canada and shuttle buses at Kennedy Airport in New York City.

Objectives: The demonstration project's goals were to learn if methanol flexible fuel vehicles can operate reliably in fleet service and to learn their emissions and fuel economy characteristics over a 100,000 mile period of use.

R & D Results: Emission tests in a simulated urban cycle showed very clean performance with M85 (85% methanol, 15% gasoline) with a 36% reduction of nitrogen oxide (NOx), a 53% reduction of carbon monoxide (CO), and a 74% reduction of organic material hydrocarbon equivalent (OMHC). Cold-start emissions of carbon monoxide were higher with methanol blends compared to gasoline. The emission of formaldehyde and methanol exhaust emissions were higher for the methanol blends during cold-start tests than during hot-start tests. For both gasoline and methanol blends, emissions of OMHC, CO, and NOx increased, though the increase was less with the methanol blends than with gasoline. Fuel composition did not affect energy-based fuel economy nor did mileage accumulation. Active catalysts seem to be more efficient than inactive catalyst in removing CO and organic emission with increased methanol content.

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METHANOL FUEL VEHICLE DEMONSTRATION: EXHAUST EMISSION TESTING

Final Report

Prepared for

THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY
Two Rockefeller Plaza
Albany, New York 12223

Senior Project Manager
Dr. Lawrence R. Hudson

and

EA ENGINEERING
FORD MOTOR COMPANY
LUBRIZOL CORPORATION
NEW YORK STATE THRUWAY AUTHORITY
ONTARIO MINISTRY OF ENERGY

Prepared by

THE NEW YORK STATE
DEPARTMENT OF ENVIRONMENTAL CONSERVATION
Automotive Emissions Laboratory
Division of Air Resources
50 Wolf Road
Albany, New York 12233-3259

Principal Investigator
James D. Hyde

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ABSTRACT

Ford Motor Company converted four stock 1986 Ford Crown Victoria sedans to methanol flexible fuel vehicles (FFVs). During 143,108 operational miles from 1987 to 1990, the FFVs underwent more than 300 dynamometer driving tests to measure exhaust emissions, catalytic activity, fuel economy, acceleration, and driveability with gasoline and methanol blend fuels.

Dynamometer driving tests included the Federal Test Procedure (FTP), the Highway Fuel Economy Test, and the New York City Cycle. Exhaust emission measurements included carbon dioxide, carbon monoxide (CO), nitrogen oxides (NO_x), non-oxygenated hydrocarbons, organic material hydrocarbon equivalent (OMHCE), formaldehyde, and methanol. Catalytic activity was based on exhaust emissions data from active and inactive catalysts.

OMHCE, CO, and NO_x were usually lower with M85 (85% methanol, 15% gasoline) than with gasoline for both active and inactive catalysts when initial engine and catalyst temperatures were at or near normal operating temperatures. CO was higher with M85 than with gasoline when initial engine and catalyst temperatures were at or near ambient temperature. Formaldehyde and methanol were higher with M85. Active catalyst FTP OMHCE, CO, and NO_x increased as vehicle mileage increased, but increased less with M85 than with gasoline. Energy based fuel economy remained almost constant with changes in fuel composition and vehicle mileage.

ACKNOWLEDGEMENTS

The New York State Energy Research and Development Authority funded this work under Cost-Sharing Agreement No. 1000-ERER-ER-88 with Dr. Lawrence R. Hudson as Senior Project Manager. The authors thank the Energy Authority for support and encouragement. The New York State Thruway Authority operated and maintained the flexible fuel vehicles at the Thruway Authority maintenance facility in Albany, NY, under the direction of Mr. Dick Kuehn to whom the authors extend thanks for cooperation and assistance in this project. The authors also thank Dr. Frank M. Black and Dr. Silvestre B. Tajada of the Environmental Protection Agency for assistance in providing materials and services for formaldehyde analyses and Mr. C. O. Davis III of NSI Technology for performing the formaldehyde analyses. EA Engineering, Science, and Technology provided technical support as a contractor to the Energy Authority. The authors thank Mr. Richard Bechtold and Mr. Mike Miller of EA Engineering, Science, and Technology for interest and assistance.

PREFACE

This report is an abridged version of the final report prepared for Agreement 1000-ERER-ER-88. The unabridged version contains more scientific and technical details of the testing procedures and results. Some of the items included in the unabridged version are: experimental description and protocol; mathematical equations used to compute experimental parameters and emissions; technical discussions concerning observations; many tables and figures; the full emissions database; and vehicle equipment modification data. Readers who desire copies of the unabridged final report should contact the Energy Authority.

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SUMMARY

Ford Motor Company converted four stock 1986 Ford Crown Victoria sedans to methanol flexible fuel vehicles. During 143,108 operational miles from 1987 to 1990 by the New York Thruway Authority, the methanol flexible fuel vehicles underwent more than 300 dynamometer driving tests at the New York Department of Environmental Conservation Automotive Emissions Laboratory to measure exhaust emissions, catalytic activity, fuel economy, acceleration, and driveability with gasoline and methanol blend fuels.

For most dynamometer tests with initial engine and catalyst temperatures at or near normal operating temperatures (hot-start tests), a fuel blend of 85 percent methanol, 15 percent special gasoline produced lower carbon monoxide, organic material hydrocarbon equivalent, and nitrogen oxide exhaust emissions than an unleaded, regular grade gasoline. Methanol blend fuels generated higher formaldehyde and methanol exhaust emissions than gasoline.

Methanol blend fuels produced the largest mass per mile exhaust emission benefits in simulated urban driving. Compared to gasoline in urban driving dynamometer tests, the 85 percent methanol, 15 percent special gasoline fuel attained the following exhaust emission reductions: 3.3 grams per mile carbon monoxide (53 percent reduction); 0.90 grams per mile organic material hydrocarbon equivalent (74 percent reduction); and 0.91 grams per mile nitrogen oxides (36 percent reduction).

In dynamometer tests with the initial engine and catalyst temperatures at or near ambient temperature (cold-start tests), methanol blend fuels caused higher carbon monoxide exhaust emissions than gasoline. Methanol blend fuels produced markedly higher formaldehyde and methanol exhaust emissions in cold-start tests than in hot-start tests.

As vehicle mileage accumulated, organic material hydrocarbon equivalent, carbon monoxide, and nitrogen oxide exhaust emissions increased, but increased less with methanol blend fuels than with gasoline.

Fuel composition did not affect energy based fuel economy. Mileage accumulation did not affect fuel economy significantly. Compared to gasoline, the 85 percent methanol, 15 percent special gasoline fuel produced slightly shorter acceleration times than gasoline.

Analysis of emission test data for active and inactive catalysts suggested that active catalysts became more efficient in removing carbon monoxide and organic emissions with increasing fuel methanol. A reduction in fuel sulfur with increasing fuel methanol may have contributed to increased catalyst activity. Because this project did not measure fuel sulfur, the effect of fuel sulfur on exhaust emissions compared to the effect of fuel methanol on exhaust emissions was undetermined. Judicious assessment of methanol flexible fuel vehicle exhaust emission data requires knowledge of fuel sulfur and exhaust emission interactions, and additional research on this subject is recommended.

Section 1
EXPERIMENTAL

VEHICLES

Ford Motor Company (Ford) modified four 1986 model year Crown Victoria sedans to operate on gasoline or methanol/gasoline blend fuels with up to 85% methanol, producing *flexible fuel vehicles* (FFVs). An optical sensor in the fuel line measured fuel methanol. An electronic control unit processed the optical sensor output signal, establishing engine operating parameters appropriate to each fuel blend.[1]

The only significant differences among the four FFVs were the individual vehicle in-use operation and service histories. During the project, some vehicle components were replaced due to malfunctions or upgraded in response to directives from Ford. (The unabridged final report provides technical data, specifications and modifications, in-use histories, and component replacement and upgrade data.) The individual FFVs were identified as 506, 507, 508, and 509 (the last three digits of the manufacturer vehicle identification numbers).

FUELS

The letter "M" and a numeral denote methanol/gasoline blend fuels according to the volume percent methanol in the fuel. For example, M85 is an 85% methanol, 15% gasoline blend, and M0 is gasoline.

Vehicles were operated and tested with both gasoline and methanol blends ranging from M20 to M85. A blending pump prepared M85 from chemical grade methanol and a special gasoline (unleaded, high volatility, high aromatic content). FFVs refueled with M85 at the blending pump. Adding unleaded, regular grade gasoline from Thruway Authority gasoline pumps to M85 in the FFV fuel tank produced fuel blends with less than 85% methanol.

In July 1987, Ford delivered all four FFVs fueled with M85, and initial exhaust emission tests were conducted with this fuel. Unfortunately, project M85 did not become available until late in 1989, after FFVs 506 and 508 each accumulated more than 50,000 miles on gasoline. FFVs 507 and 509 accumulated approximately 1600 and 9800 miles, respectively, prior to the availability of project M85.

TEST PROGRAM

The test program protocol consisted of five segments: computerized diagnostic examination, dynamometer driveability tests, dynamometer acceleration performance tests, dynamometer exhaust emission tests with active catalysts, and dynamometer emission tests with inactive catalysts. A computerized diagnostic analyzer confirmed nominal operating parameters prior to dynamometer testing. Driveability testing checked for problems such as stalling, hesitation, and surging (no significant driveability problems were encountered). Dynamometer tests measured acceleration over two speed ranges. Exhaust emission tests measured carbon dioxide, carbon monoxide (CO), nitrogen oxides (NO_x), organic species as non-oxygenated hydrocarbons (NOHC)† and organic material hydrocarbon equivalent (OMHCE)‡, formaldehyde, and methanol over different dynamometer driving cycles. Inactive catalyst emission tests (beginning in the second year of this study) provided data to

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† A redundant term used to emphasize the exclusion of oxygenated organic species (*e.g.*, methanol and formaldehyde) from this exhaust emissions category.

‡ A mass exhaust emissions entity defined by EPA:[2]

$$OMHCE_{mass} = NOHC_{mass} + \left[\frac{13.8756}{32.042} \times methanol_{mass}\right] + \left[\frac{13.8756}{30.0262} \times formaldehyde_{mass}\right]$$

calculate a catalytic activity parameter. The inactive catalysts, supplied by Ford, contained no precious metals, but were otherwise identical with active catalysts.

Exhaust emission testing used the Federal Test Procedure (FTP), the Highway Fuel Economy Test (HFET), the New York City Cycle (NYCC), and an idle performed with the transmission in drive and the brake engaged. The FTP is the Environmental Protection Agency (EPA) prescribed protocol for new vehicle emissions certification and has three discrete driving cycles: BAG1 (a cold start[†] cycle), BAG2, and BAG3 (a hot start[‡] repeat of BAG1). FTP exhaust emissions are a weighted average of exhaust emissions in the three component cycles. The HFET is the EPA standard protocol for highway fuel economy determination. The NYCC simulates driving in congested urban traffic. (Additional information on the driving cycles is provided in the unabridged final report.)

EXHAUST EMISSION TESTING EQUIPMENT AND MEASUREMENT METHODS

The emission testing equipment and measurement methods generally conformed to EPA protocol. Some exceptions and modifications were necessary to accommodate available equipment or to improve data quality. (The unabridged final report gives a complete description of the equipment and the calculations used to measure and compute test parameters and emissions.)

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† In cold start exhaust emission tests, the engine and catalyst are at or near ambient temperature, approximately 68°F in this project.

‡ In hot start exhaust emission tests, the engine and catalyst are at or near operating temperature.

Section 2
EXHAUST EMISSION OBSERVATIONS

ACTIVE CATALYST OMHCE, NOHC, CO, AND NO_x EMISSIONS†

Table 1 and Figure 1 present the average active catalyst OMHCE, NOHC, CO, and NO_x emissions for FFVs 506 and 508 by fuel type and driving cycle, obtained in tests after 50,000 miles of gasoline operation. Duplicate emission tests on each FFV with gasoline and M85 (4 data points for each fuel and driving cycle) and duplicate emission tests of FFV 506 with M60 (2 data points for each driving cycle) comprise the database for Table 1 and Figure 1.

Table 2 presents the emission reductions (or increases)‡ observed with methanol blend fuels in absolute and percentage terms. Table 2 also indicates the statistical significance of the reductions. A 99% confidence level test (described in the unabridged final report) determined statistical significance. M85 OMHCE, CO, and NO_x reductions in BAG2, BAG3, the HFET, and the NYCC were statistically significant.

The NYCC generates more emissions per mile than the FTP and the HFET. Not unexpectedly then, the gram per mile (g/mile) emission reductions with M85 were greatest in the NYCC: OMHCE, 0.90 g/mile (74%); CO, 3.29 g/mile (53%); and NO_x, 0.91 g/mile (36%). Each reduction was statistically significant. The reductions observed with M60 in the NYCC, however, were not statistically significant.

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† In this report, the term "emissions" and the singular use of specific emissions species (*e.g.*, FTP CO) always refer to *exhaust emissions*, not to emissions from non-exhaust (*e.g.*, evaporative) sources.

‡ The terms "emission reductions" and "emission increases" (or simply "reductions" or "increases") mean differences between methanol blend and gasoline emissions.

TABLE 1. ACTIVE CATALYST GRAMS PER MILE EMISSIONS

FFVs 506 & 508, AVERAGE DATA AFTER 50K MILES GASOLINE OPERATION

EMISSION	FUEL	BAG1	BAG2	BAG3	FTP	HFET	NYCC
OMHCE	GASOLINE	1.15	0.47	0.51	0.62	0.16	1.22
	M60	0.94	0.26	0.33	0.42	0.08	0.96
	M85	1.20	0.12	0.16	0.35	0.04	0.32
NOHC	GASOLINE	1.15	0.46	0.50	0.62	0.16	1.21
	M60	0.74	0.24	0.28	0.36	0.08	0.84
	M85	0.37	0.08	0.10	0.15	0.02	0.24
CO	GASOLINE	5.07	1.28	2.84	2.49	0.36	6.23
	M60	7.92	0.43	2.00	2.41	0.13	4.14
	M85	9.03	0.16	1.13	2.26	0.07	2.94
NOx	GASOLINE	1.83	1.05	1.41	1.31	0.90	2.52
	M60	1.45	0.78	1.24	1.04	0.78	2.24
	M85	1.28	0.64	1.01	0.87	0.67	1.61

TABLE 2. ACTIVE CATALYST EMISSION MASS AND PERCENTAGE CHANGES COMPARED TO GASOLINE FOR M60 AND M85

FFVs 506 & 508, AVERAGE DATA AFTER 50K MILES GASOLINE OPERATION

EMISSION	FUEL	BAG1	BAG2	BAG3	FTP	HFET	NYCC
OMHCE	M60	-0.22 -19%	-0.20 -43%	-0.18 -35%	-0.19 -31%	-0.07 -45%	*-0.26* *-21%*
	M85	*0.05* *4%*	-0.35 -75%	-0.35 -69%	-0.27 -44%	-0.12 -77%	-0.90 -74%
CO	M60	2.84 56%	*-0.85* *-67%*	*-0.85* *-30%*	*-0.08* *-3%*	-0.23 -64%	*-2.08* *-33%*
	M85	3.96 78%	-1.12 -88%	-1.72 -60%	*-0.23* *-9%*	-0.29 -81%	-3.29 -53%
NOx	M60	*-0.38* *-21%*	-0.27 -26%	*-0.18* *-13%*	-0.27 -21%	-0.11 -12%	*-0.28* *-11%*
	M85	-0.55 -30%	-0.41 -39%	-0.40 -28%	-0.44 -34%	-0.22 -25%	-0.91 -36%

Italic numbers indicate differences in mean values that were not statistically significant at the 99% confidence level, i.e., the null hypothesis (that the difference between the methanol fuel mean emission and the gasoline mean emission was zero) could not be rejected at the 99% confidence level; other values represent statistically significant differences, i.e., the null hypothesis was rejected at the 99% confidence level.

SHADED numbers emphasize an increase, rather than a reduction, in emissions with methanol fuel relative to gasoline fuel.

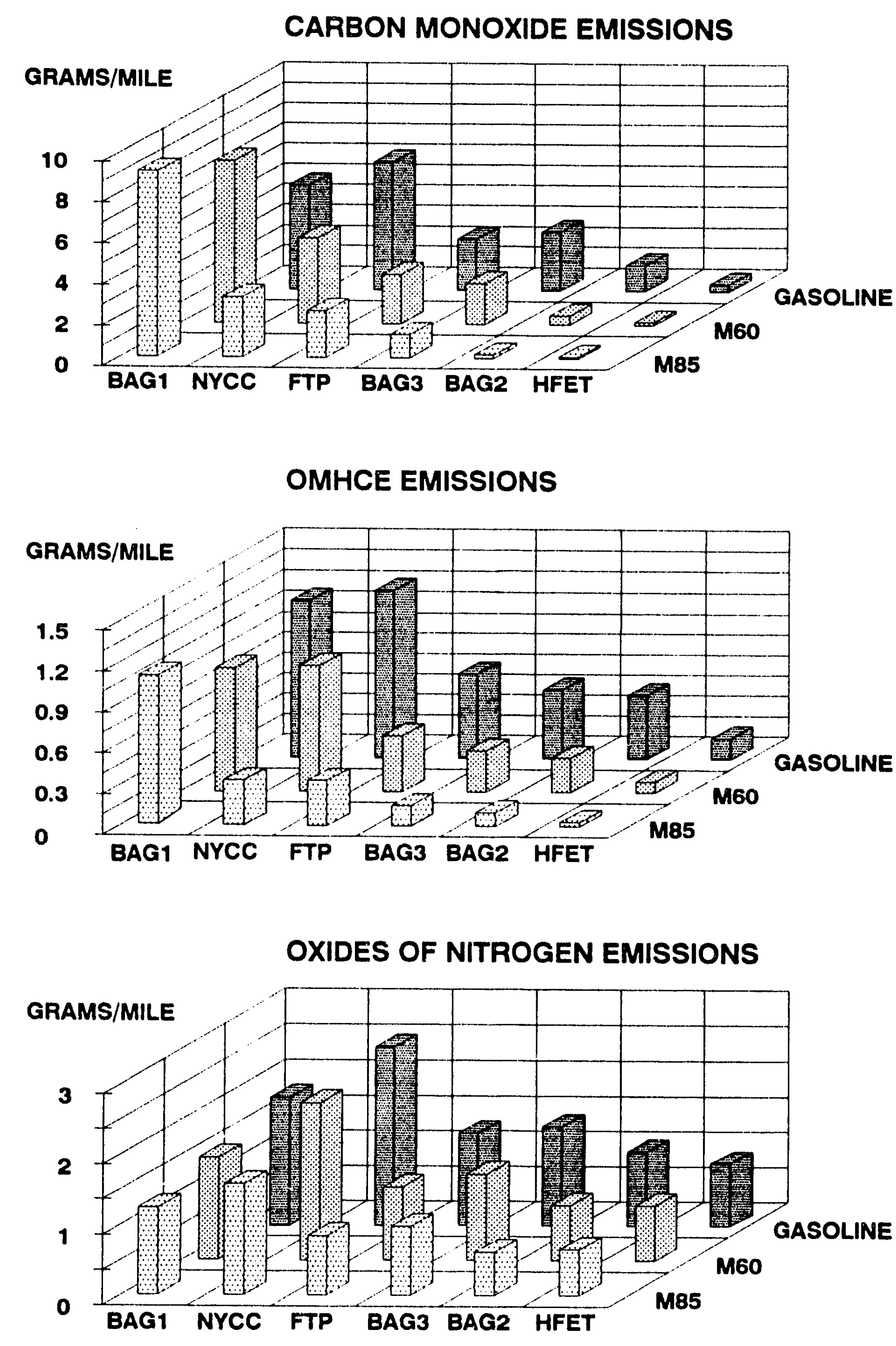

FIGURE 1. ACTIVE CATALYST EXHAUST EMISSIONS
FFVs 506 & 508 AFTER 50K MILES GASOLINE OPERATION

Emission rates are low in the HFET; therefore, the g/mile reductions observed with M85 in the HFET were small. Nonetheless, the reductions were statistically significant and comparatively high in percentage terms: OMHCE, 0.12 g/mile (77%); CO, 0.29 g/mile (81%); and NO_x, 0.22 g/mile (25%). HFET emission reductions with M60 were less than with M85, but were statistically significant.

M85 produced statistically significant OMHCE, CO, and NO_x reductions in BAG2 and BAG3. In BAG1, however, both M85 and M60 produced statistically significant CO *increases*: 3.96 g/mile (78%) and 2.84 g/mile (56%), respectively.

M85 and M60 FTP OMHCE and NO_x reductions were statistically significant: OMHCE, 0.27 g/mile (44%) and 0.19 g/mile (31%); NO_x, 0.44 g/mile (34%) and 0.27 g/mile (21%). The CO increases in BAG1 with both M85 and M60 offset BAG2 and BAG3 CO reductions to produce comparatively small, and not statistically significant, FTP CO reductions for M85 and M60.

In summary, comparing M85 and gasoline emissions, M85 produced the following statistically significant effects: NO_x reductions in all cycles; OMHCE reductions in all cycles except BAG1; CO reductions in BAG2, BAG3, the HFET, and the NYCC; and a CO increase in BAG1.

The unique initial conditions in BAG1, compared to the other driving cycles used in this project, caused CO increases with M85. BAG1 begins with the test vehicle engine off and the engine and catalyst at ambient temperature. The other project driving cycles begin with the engine on (except BAG3) and the catalyst at or near operating temperatures. Emissions with the engine and catalyst below operational temperatures are inherently higher than emissions at operational temperatures. In addition, increasing fuel methanol lowers fuel volatility, which requires greater fuel enrichment during the engine and catalyst warmup. Fuel enrichment usually increases CO and organic emissions.

Figures 2 and 3 present linear regression trend lines for OMHCE, CO, and NO_x emissions versus fuel methanol by driving cycle. The trend lines suggest increasing emission reductions with increasing fuel methanol in all cycles except BAG1. In BAG1 the trend lines suggest an increase in CO and almost constant OMHCE.

INACTIVE CATALYST OMHCE, NOHC, CO, AND NO_x EMISSIONS

Dynamometer emission tests conducted with inactive catalysts also indicated a general trend toward reduced emissions as fuel methanol increased, except CO in BAG1, which was approximately constant. (The unabridged final report provides complete inactive catalyst emission data.)

CATALYST ACTIVITY

A "catalyst activity parameter", based on the ratio of inactive to active catalyst emissions, suggested that increasing fuel methanol enhanced catalytic activity for CO and OMHCE in BAG2, BAG3, the HFET, and the NYCC. The NO_x catalyst activity parameter did not show a discernible trend with increasing fuel methanol. (Possible mechanisms for these phenomena are presented in the unabridged final report.)

Because sulfur adversely affects catalytic activity, fuel sulfur may have been a confounding factor in emission reductions and catalyst activity. The M85 sulfur content was almost certainly less than that of the unleaded, regular grade gasoline. Unfortunately, fuel sulfur was not measured. Without fuel sulfur measurements, this project could not determine if fuel sulfur effects were significant compared to fuel methanol effects. Fuel sulfur effects in methanol FFVs merit additional research.

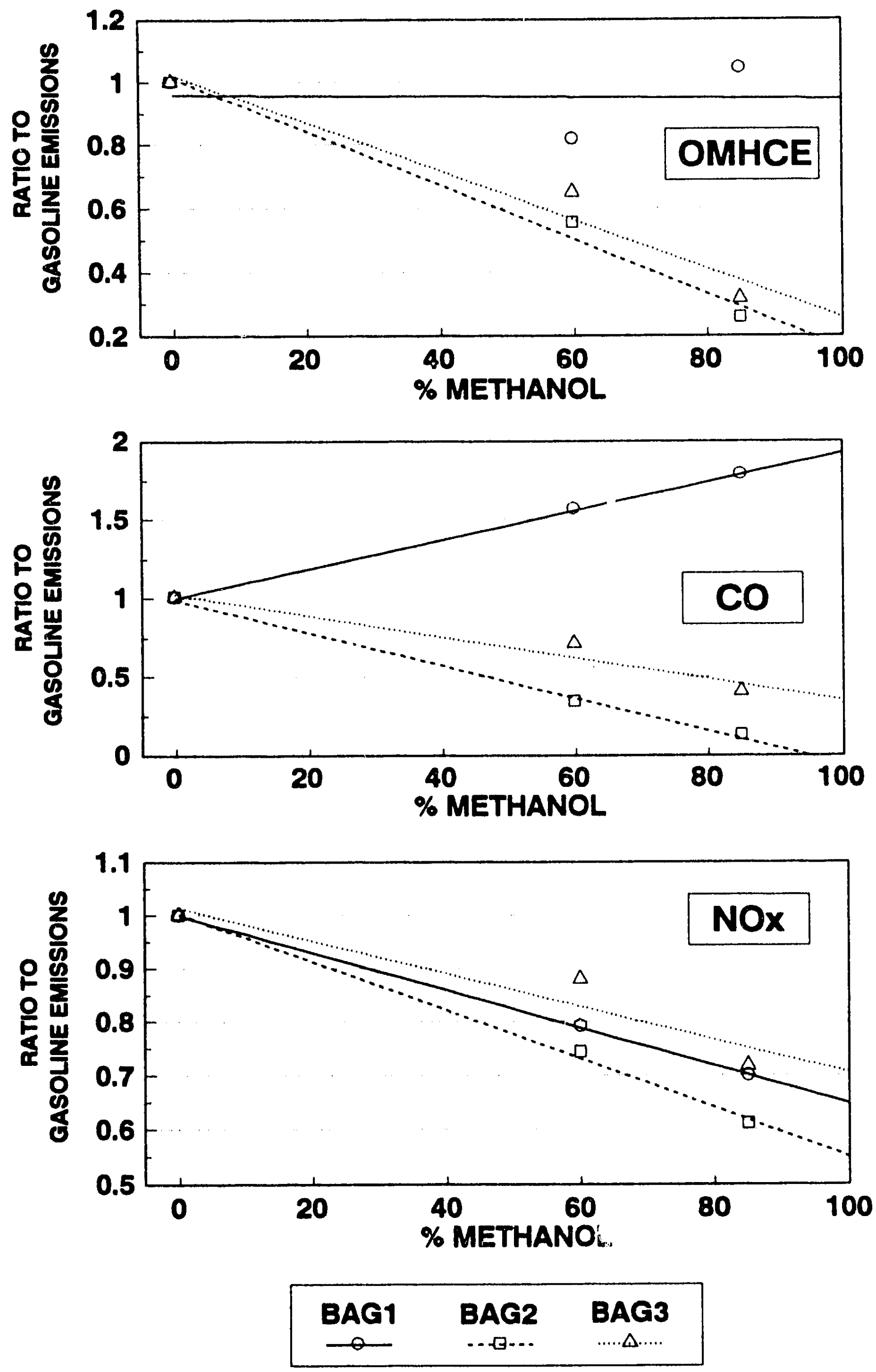

FIGURE 2. ACTIVE CATALYST EXHAUST EMISSIONS : NORMALIZED TO GASOLINE EMISSIONS FFVs 506 & 508 AFTER 50K MILES GASOLINE OPERATION

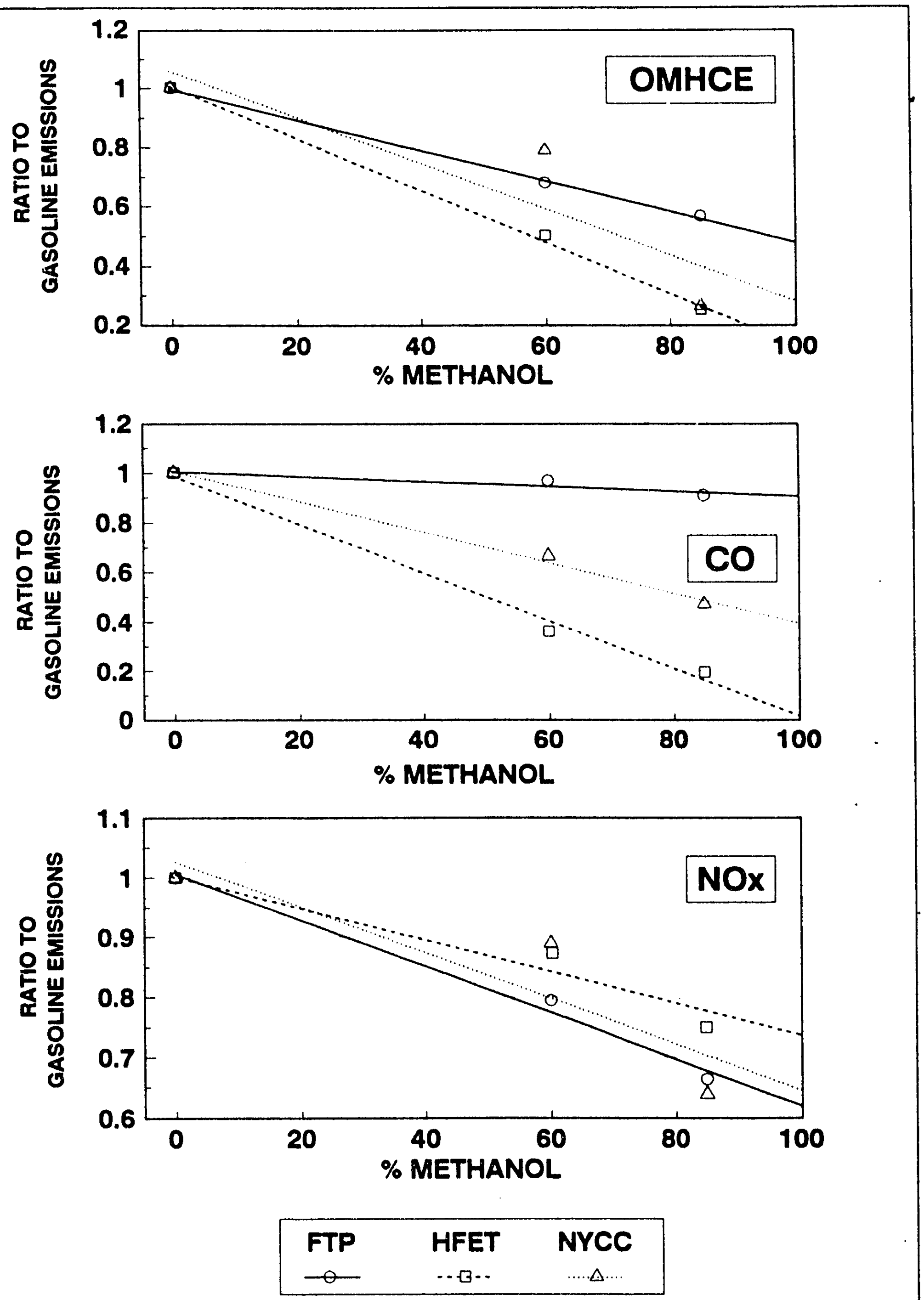

FIGURE 3. ACTIVE CATALYST EXHAUST EMISSIONS : NORMALIZED TO GASOLINE EMISSIONS FFVs 506 & 508 AFTER 50K MILES GASOLINE OPERATION

CERTIFICATION STANDARDS AND MILEAGE ACCUMULATION OBSERVATIONS

Table 3 gives the Tier 0 standards that apply to the project FFVs and additional emission standards for later model year methanol light-duty vehicles.[3,4] Figure 4 presents the effect of mileage accumulation on active catalyst FTP emissions. Judging from the linear regression trend lines in Figure 4, gasoline OMHCE remained below the 0.41 g/mile Tier 0 limit† only through 15,000 miles, and M85 OMHCE remained below the Tier 0 limit through 60,000 miles. CO remained below the 3.4 g/mile Tier 0 limit through 60,000 miles with both gasoline and M85, but the trend lines suggest that gasoline CO increased with accumulated mileage at a greater rate than M85 CO. For NO_x, all gasoline data exceeded the 1.0 g/mile Tier 0 limit, and all M85 data fell below the Tier 0 limit.

TABLE 3. FEDERAL EXHAUST EMISSION CERTIFICATION STANDARDS (g/mile) FOR LIGHT-DUTY METHANOL VEHICLES

(extracted from references 3 and 4)

EMISSION SPECIES	TIER 0 MY '81-'93 (50K miles)	TIER 1 MY '96+ (50K / 100K miles)	CLEAN FUELS PROGRAM MY '96-'00 (50K / 100K miles)
OMHCE or NMOG[1]	0.41 (OMHCE)	0.41 / -- (OMHCE)	0.125 / 0.156 (NMOG)
OMNMHCE[2]	--	0.25 / 0.31	--
CO	3.4	3.4 / 4.2	3.4 / 4.2
NOx	1.0	0.4 / 0.6	0.4 / 0.6
FORMALDEHYDE	--	--	0.015 / 0.018
PARTICULATE MATTER	0.20 (diesel cycle) -- (Otto cycle)	0.08 / 0.10	-- / 0.08 (diesel cycle) -- (Otto cycle)

1 non-methane organic (NMOG) emissions : the sum of nonoxygenated and oxygenated organic species, excluding methane; minimally including all oxygenated species with five or fewer carbon atoms, and all known alkanes, alkenes, alkynes, and aromatics with twelve or fewer carbon atoms
2 organic material non-methane hydrocarbon equivalent

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† The Tier 0 standard for gasoline vehicles is 0.41 g/mi "total hydrocarbons", which closely approximates 0.41 g/mi OMHCE for gasoline vehicles.

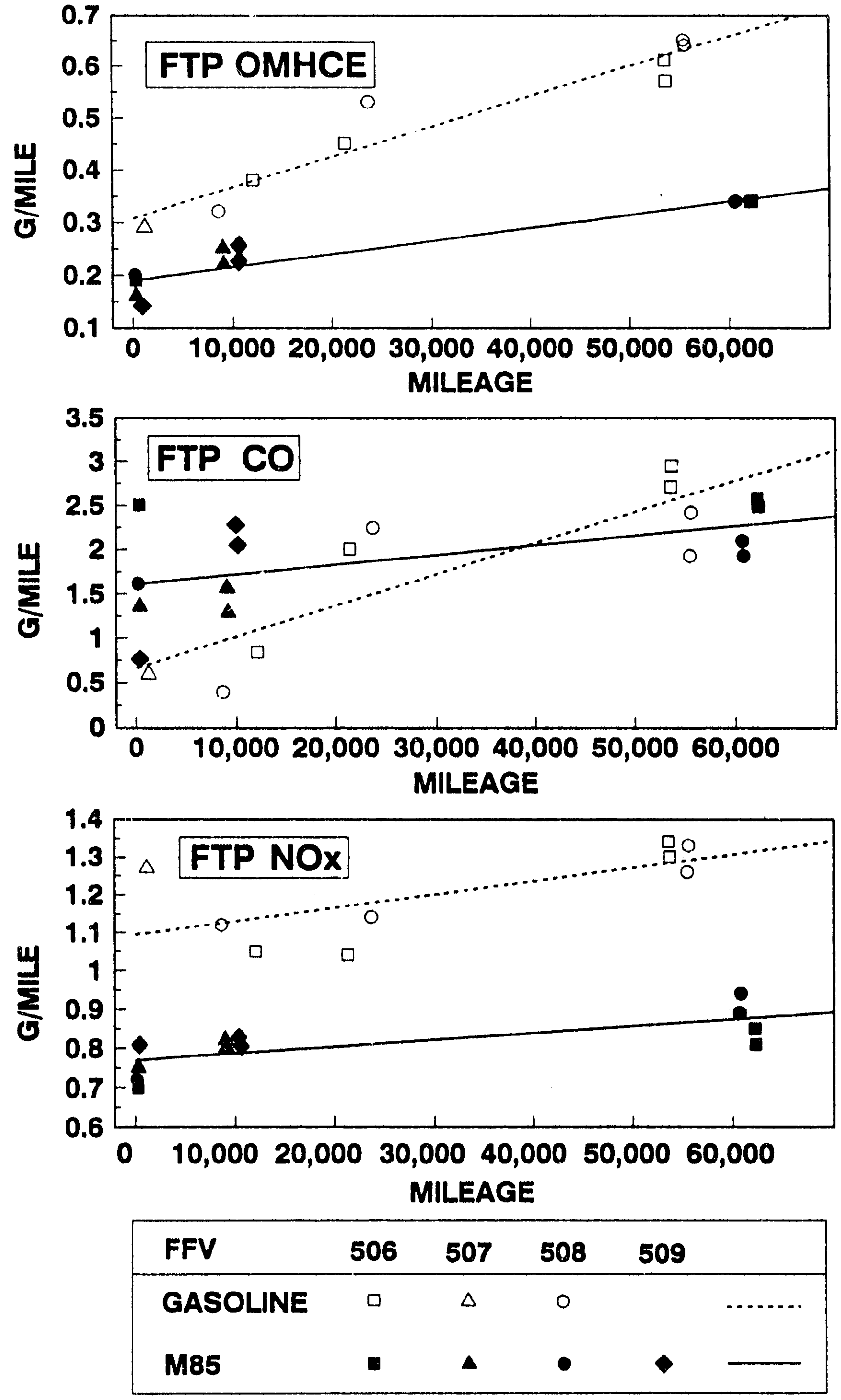

FIGURE 4. FTP EXHAUST EMISSIONS vs. MILEAGE FOR INDIVIDUAL FFVs WITH GASOLINE AND M85 FUELS

As the FFVs accumulated 60,000 miles, the M85 and gasoline CO emission relationships were distinctly different in BAG1, BAG2, and BAG3 (data presented in the unabridged final report). In BAG1, the CO-mileage regression trend lines were nearly parallel with M85 CO about 3.5 g/mile higher than gasoline CO. In BAG2, M85 CO remained less than 0.2 g/mile as gasoline CO increased from less than 0.5 g/mile to more than 1.25 g/mile. In BAG3, the M85 trend was slightly negative, from about 1.5 g/mile to about 1 g/mile, as the gasoline CO trend increased from about 0.5 g/mile to about 3.25 g/mile.

A composite hot start catalytic activity parameter (see unabridged final report) suggested a decrease in catalytic activity for OMHCE and CO with mileage accumulation with both gasoline and M85, but a lesser *rate of decrease* with M85.

FORMALDEHYDE AND METHANOL EMISSIONS

Light-duty vehicles subject to Federal regulation will not be required to meet formaldehyde emission standards until 1996. In California, light-duty vehicle formaldehyde emission regulations began in 1993.

Methanol emission regulations are unlikely, given present understanding of ambient atmospheric methanol in photochemical smog reactions and public health. However, OMHCE emission calculations include both formaldehyde and methanol emissions, and the emission rate of each species is of interest to air pollution and automotive researchers.

For FFVs 506 and 508 at more than 60,000 miles, M85 formaldehyde emissions in BAG1, the NYCC, and the FTP were 0.164 to 0.189 g/mile, 0.062 to 0.086 g/mile, and 0.065 to 0.090 g/mile, respectively. At about 53,600 miles, FFV 506 formaldehyde emissions with gasoline ranged from 0.004 to 0.016 g/mile. (Additional formaldehyde data are available in the unabridged final report.)

Similarly, for FFVs 506 and 508 at more than 60,000 miles, M85 methanol emissions in BAG1, the NYCC, and the FTP were 1.50 to 1.93 g/mile, 0.138 to 0.200 g/mile, and 0.368 to 0.420 g/mile, respectively. At about 53,600 miles, FFV 506 methanol emissions with gasoline were less than 0.006 g/mile. (Additional methanol data are available in the unabridged final report.)

Section 3
FUEL ECONOMY

FUEL ECONOMY CALCULATIONS

A carbon mass balance method calculated volumetric fuel economy (VFE) using the fuel carbon content and the exhaust emission rate of carbon species. Because methanol has less energy per unit volume than gasoline, methanol blend VFE is lower than gasoline VFE.

Energy based fuel economies are used frequently to compare fuels with different energy densities. A gasoline equivalent fuel economy (GEFE), defined as the miles driven per equivalent energy gasoline volume, was calculated for project FFVs. (A detailed description of fuel economy calculations and the necessary assumptions and estimations involved may be found in the unabridged final report.)

FUEL ECONOMY RESULTS

Figure 5 presents M85 and gasoline FTP VFE versus accumulated mileage for each FFV. Figure 6 shows the decrease in FTP, HFET, and NYCC VFE as fuel methanol increased for FFVs 506 and 508 (after 50,000 miles of gasoline operation).

FTP VFE was between 16.8 and 18.6 miles per gallon (mpg) with gasoline and between 9.9 and 10.8 mpg with M85. The M85 HFET VFE was approximately 16 mpg, compared to almost 28 mpg with gasoline. M85 VFE was approximately 60% of the gasoline VFE for all driving cycles.

Figure 7 presents GEFE data (using both lower and higher heating values, as explained in the unabridged final report) for methanol blend fuels in the FTP, HFET, and NYCC. The GEFE values were essentially independent of fuel methanol.

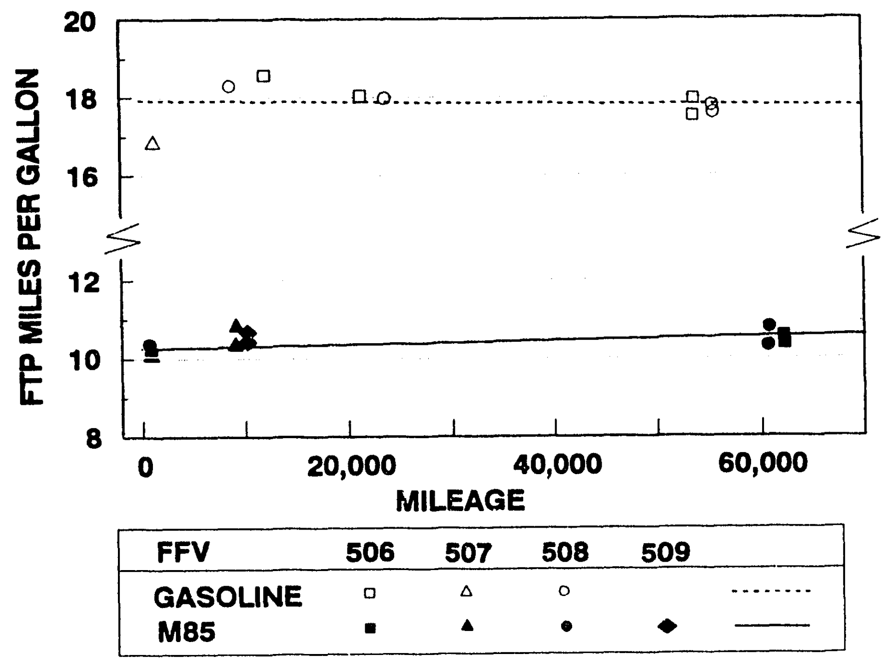

FIGURE 5. FTP VOLUMETRIC FUEL ECONOMY vs. MILEAGE FOR GASOLINE AND M85

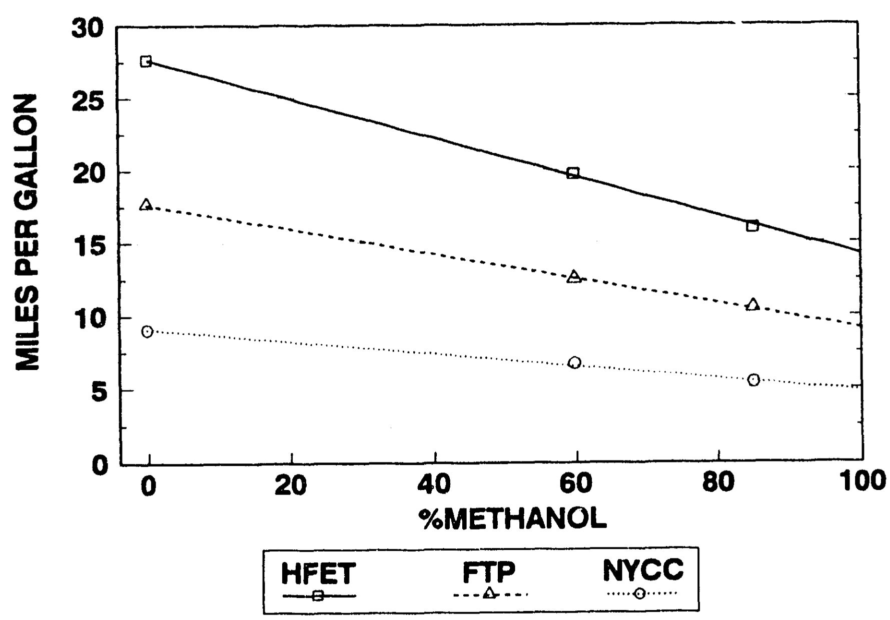

FIGURE 6. VOLUMETRIC FUEL ECONOMY vs. METHANOL FFVs 506 & 508 AFTER 50K MILES GASOLINE OPERATION

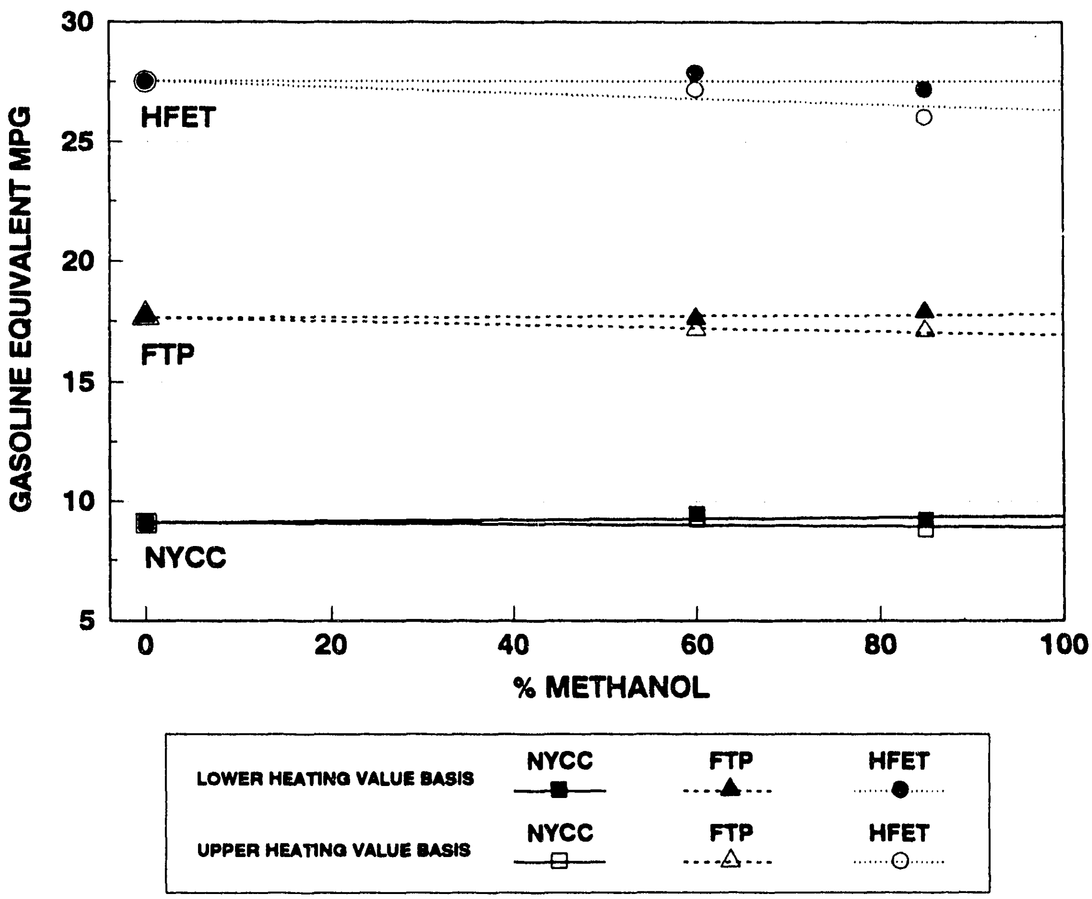

FIGURE 7. GASOLINE EQUIVALENT FUEL ECONOMY FFVs 506 & 508 AFTER 50K MILES GASOLINE OPERATION

Section 4

ACCELERATION TESTING

ACCELERATION TEST METHOD

Wide-open throttle accelerations from 10 mph to 70 mph and 30 mph to 70 mph on the chassis dynamometer measured acceleration. Tire slippage on the dynamometer rollers invalidated acceleration times from 0 mph. Acceleration tests were conducted with gasoline and methanol blend fuels.

ACCELERATION TEST RESULTS

Initial observations with gasoline and methanol blend fuels for single acceleration tests exhibited no apparent methanol effects, but the data showed considerable scatter, and mileage accumulation may have been a confounding factor. Replicate 10 to 70 mph tests were conducted with FFVs 506 and 508 using both gasoline and M85, after accumulating greater than 50,000 miles on each FFV. The mean acceleration times with M85 were 15.93 and 15.15 seconds for FFV 506 and 508, respectively, compared with gasoline mean acceleration times of 16.40 and 15.72 seconds for FFVs 506 and 508, respectively. The differences were statistically significant at the 90% confidence level, indicating that a slight improvement in acceleration with M85 compared to gasoline was probable.

Section 5

CONCLUSIONS

CAVEATS

The following conclusions were based on limited and vehicle specific data. Unless otherwise stated, the conclusions refer to active catalyst emission test results. Furthermore, the conclusions assume that, for the fuels and vehicles in this project, fuel methanol had a significantly greater effect than fuel sulfur on emissions and catalytic activity.

METHANOL EFFECTS

- M85 resulted in the following statistically significant emission reductions: NO_x in all cycles; OMHCE in all cycles except BAG1; CO in all cycles except BAG1 and the FTP.

- M85 resulted in the following statistically significant emission reductions with inactive catalysts: NO_x in all cycles except BAG2; OMHCE in all cycles except BAG1 and the NYCC; CO in the HFET and the NYCC.

- M85 increased CO and OMHCE catalyst activity in all cycles except BAG1.

- M85 increased formaldehyde and methanol emissions in all cycles and increased CO in BAG1.

- As fuel methanol increased, VFE decreased, but GEFE did not change significantly.

- M85 decreased acceleration times slightly.

MILEAGE ACCUMULATION EFFECTS

- OMHCE, CO, and NO_x emissions increased with increasing mileage, but the rate of increase was less with M85 than with gasoline.

- Formaldehyde emissions increased as mileage increased with methanol blends.

- Composite hot-start catalyst activity for OMHCE and CO decreased with mileage accumulation, but the rate of decrease was less with M85 than with gasoline.

- Mileage accumulation had little or no effect on VFE and GEFE.

DRIVING CYCLE EFFECTS

- CO, OMHCE, and NO_x emissions increased in the following order: HFET $<$ BAG2 $<$ BAG3 $<$ FTP $<$ BAG1. NYCC emissions were greater than FTP emissions, but less than or greater than BAG1 emissions, depending on emission species and fuel composition.

- Cold start BAG1 CO emissions increased with increasing fuel methanol, in contrast to warm start cycle CO emissions, which decreased with increasing fuel methanol.

- Mass basis M85 OMHCE, CO, and NO_x emission reductions were largest in the NYCC.

- Percentage basis M85 OMHCE emission reductions were similar in all hot-start driving cycles.

- Percentage basis M85 CO emission reductions were largest in BAG2 and the HFET.

- Percentage basis M85 NO_x emission reductions were largest in BAG2 and the HFET.

FORMALDEHYDE AND METHANOL EMISSIONS

- M85 in BAG1 produced the highest formaldehyde and methanol emissions. With M85, NYCC and FTP formaldehyde emissions were comparable in magnitude, and higher, in each case, than in the HFET. Methanol emissions were lowest in the HFET, and generally higher in the FTP than in the NYCC.

Section 6

RECOMMENDATIONS

Further study of FFV emissions is recommended, specifically:

- Quantifying the effects of fuel composition (particularly fuel sulfur) on emissions and fuel economy.
- Exhaust emission testing of dedicated gasoline vehicles of the same model and engine type as the FFVs.
- Exhaust emission testing of FFVs with the special (high volatility, high aromatic) gasoline used in formulating M85.
- Exhaust emission testing of a larger fleet of FFVs to increase the size of the emissions database.
- Exhaust emission testing through 100,000 miles of vehicle operation to evaluate exhaust emission control deterioration throughout vehicle lifetime.
- Cold-start exhaust emission testing at outdoor winter temperatures to determine the impact of fuel methanol on cold climate emissions from methanol FFVs.

Section 7

REFERENCES

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