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Results from the First Year of Operation of the Federal Methanol Fleet at Oak Ridge National Laboratory

R. N. McGill
B. H. West
S. L. Hillis
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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Engineering Technology Division

RESULTS FROM THE FIRST YEAR OF OPERATION OF THE FEDERAL METHANOL FLEET AT OAK RIDGE NATIONAL LABORATORY

R. N. McGill
B. H. West
S. L. Hillis*
J. W. Hodgson*

*University of Tennessee

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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CONTENTS

LIST OF FIGURES

LIST OF TABLES

RESULTS FROM THE FIRST YEAR OF OPERATION OF THE FEDERAL METHANOL FLEET AT OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

The Oak Ridge National Laboratory has completed over one full year of operation of ten vehicles for the Federal Methanol Fleet Project; five of the vehicles are fueled with methanol. Nearly 100,000 miles were accumulated on the vehicles in a nearly trouble-free operation during the first year. Energy consumption for the methanol cars was slightly higher than for the gasoline cars, most likely as a result of shorter average trip lengths for the methanol cars. Iron and lead have accumulated at a greater rate in the lubricating oil of the methanol cars. Drivers ratings of vehicles reflected some dissatisfaction with the cold-weather performance of the methanol cars, but the cars have no special provisions for cold weather. Otherwise, drivers' ratings have been very similar between methanol and gasoline cars.

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1. INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

Oak Ridge National Laboratory (ORNL) has operated ten vehicles for a period of over one year for the Department of Energy's Federal Methanol Fleet Project; five of the cars are methanol-powered and five are comparable gasoline vehicles. This report details the operation and results of the project for its first full year. Other reports[1-5] have detailed results from the two other fleets involved in the project, located at Lawrence Berkeley Laboratory and Argonne National Laboratory. Because much of the background of this project has been described in those reports, it will not be discussed at any length in this report. The reader is encouraged to refer to the earlier reports for those details. This report will deal primarily with the description and characteristics of the fleet at ORNL and the results from its first year.

The ORNL fleet actually began operation in mid-1987 with the receipt of five gasoline vehicles, while five methanol vehicles arrived in late 1987 after they had been converted to methanol and undergone emissions tests. The period of time for this report is through December 31, 1988, thus representing about one year for the methanol vehicles and about one and one-half years for the gasoline vehicles.

The cars at ORNL are all 1987 Buick Regal coupes with 3.8 liter V-6 engines and turbochargers. Five of them were converted to operate on methanol by Michigan Automotive Research Corporation in Ann Arbor in the fall of 1987. Except for the fuel systems, the methanol and gasoline cars are otherwise similarly equipped.

Methanol fuel used at ORNL is nominally M85 (85% methanol and 15% regular unleaded gasoline, the coal-derived methanol being purchased from Eastman Chemical Products, Inc., in Kingsport, TN). An existing underground storage tank, previously used for gasoline and/or diesel fuels, was reclaimed and restored to operation for the methanol fuel after having been unused for some time. Appropriate fuel lines and a dispensing pump were installed to complete the methanol fueling station.

Nine of the Buicks are assigned to individual research divisions within ORNL and are used to supplement routine fleet vehicles; one of the cars is assigned to the Oak Ridge Operations Office of the Department of Energy. All are used for transportation around the Oak Ridge area, between plant sites, and for occasional out-of-town trips.

A small amount of data is recorded by ORNL drivers for each trip taken in any of the ten vehicles, and they also rate the vehicle's ease of starting and driveability. Fueling data and maintenance records are kept by the ORNL motor pool personnel. The lubricating oil of each of the ten vehicles is sampled nominally every 1000 miles (more frequent than the 3000 mile oil change interval) and sent to a laboratory where it is analyzed for wear metal content, fuel dilution, base number, etc.

1.2 SUMMARY

The methanol fleet operating at ORNL has completed a satisfactory first full year of operation and is well into its second year. The ten cars accumulated a total of nearly 100,000 miles with very little difficulty. Energy consumption for the five methanol cars was slightly higher than that of the five gasoline cars, but their trip lengths averaged only about two-thirds that of the gasoline cars. Except for a problem with some of the special methanol fuel pumps (which should not have been expected), the methanol cars had very few problems that resulted from the methanol engine systems. This made the statistics of maintenance compare very well between methanol and gasoline cars. Iron and lead have accumulated at greater rates in the oil of the methanol cars but not so much greater as to cause alarm. Drivers rated the driveability of the methanol cars virtually the same as that of the gasoline cars, but they rated the ease of starting of the methanol cars somewhat lower. Ease of starting of the methanol cars clearly suffered in the colder months of the year, but these cars have no special systems for cold weather starting. Only on the very coldest of days in Oak Ridge were there great problems with starting the methanol cars.

2. OAK RIDGE NATIONAL LABORATORY FLEET

Oak Ridge National Laboratory is one of three facilities operated in Oak Ridge, Tennessee, by Martin Marietta Energy Systems, Inc., for the Department of Energy. Vehicles involved in this project are located at two of the sites, and the methanol refueling facility is located at the third. Much of the cars' use involves driving within and between these three sites, each of which is approximately 8 miles from the others. Weather in East Tennessee is generally moderate to warm, but winters can include a number of extremely cold days, a factor which influences methanol vehicle performance and driver acceptance. Figure 1 shows two of the ORNL methanol fleet vehicles.

2.1 METHANOL VEHICLE DESCRIPTION

Converting the Buicks to methanol by Michigan Automotive Research Corporation was patterned after a conversion that the company had provided BP America (formerly Standard Oil of Ohio) a few years earlier.[6] Major elements of the conversion are as follows:

Fuel Tank: Increased capacity to approximately 30 gallons. Constructed of 304 Stainless steel for shell, internal baffling, and pump reservoir. Production filler neck was retained and nickel-plated.

Fuel Pumps: Dual Bosch KP3 in-tank fuel pumps supplied originally with the cars and replaced later with prototype methanol-compatible pumps by Bosch rated at approximately 100 gallons per hour (total for both pumps) at 3.8 bar (55 psig).

Fuel Rail: Production fuel rail retained but nickel-plated for corrosion protection.

Fuel Pressure Regulator: Higher pressure (3.8 bar); otherwise similar to stock regulator.

Fuel Injectors: Prototype Bosch injectors capable of 620 cc/min at 3.8 bar.

Cylinder Heads: Valves replaced for improved flow and swirl. Exhaust valve seats hardened.

Piston Rings: Top rings replaced with ductile iron/chrome faced rings. Other rings retained (stock).

Spark Plugs: Replaced with colder range AC R41TS plugs.

ORNL—PHOTO 3730—89

Fig. 1. ORNL Buick Regals.

Transmission: Aftermarket shift kit installed for firming up gear shifts.

EGR Programming: Rates of EGR reduced by large percentage. (NOx emissions were affected, but resources did not allow for iterative, optimizing procedure to minimize NOx emissions with reduced EGR.)

Spark Advance: Reprogrammed appropriately for methanol. Spark advance retarded significantly during cranking for enhanced cold-start performance.

No special provisions other than programming changes in the on-board computer were incorporated for cold-start performance of these vehicles even though the winter weather in Oak Ridge is occasionally cold enough to create problems with starting them. (This is different from the fleet operating under this program at Argonne National Laboratory where sophisticated systems were incorporated on the methanol vehicles to aid in cold-starting.[5]) Resources were not available for the systems that could be required on the ORNL cars for cold weather, and it was felt that the incidence of such cold weather is infrequent enough so as not to warrant an expensive development program for added systems.

2.2 LUBRICATING OIL, OIL CHANGE AND SAMPLING INTERVALS

Lubricating oil for the methanol Buicks has been supplied by the Lubrizol Corporation and is a 10W-30 multi-grade oil with an additive intended to reduce engine wear and corrosion that may be caused by the methanol fuel. The gasoline Buicks use a standard multi-grade lubricating oil recommended by General Motors for these turbocharged vehicles. The particular oil selected for the gasoline cars is Valvoline Turbo V (SF,CD/CC 10W-30).

Oil change interval for all ten cars in the fleet is set at 3000 miles, and the oil is sampled at 1000 mile intervals for laboratory analyses of wear metals, base number, fuel dilution, etc.

3. RESULTS

3.1 EMISSIONS

Two of the methanol Buicks were tested for emissions at the Environmental Protection Agency's (EPA) Motor Vehicle Emissions Laboratory in Ann Arbor, Michigan. Tests were conducted shortly after the cars had been converted to methanol, before they were shipped to ORNL. Both cars had accumulated less than 1000 miles at the time they were tested.

The EPA technicians reported "negligible" boost pressures from the engines' turbochargers over the Federal Test Procedure (FTP) driving cycle.[7] Factors that might be expected to influence the emissions from the methanol cars as compared to their gasoline counterparts include:

- Different fuel injectors which may produce different atomization and fuel/air mixing
- Higher turbocharger boost pressures (except, as noted above, the FTP cycle resulted in negligible boost values.)
- Modified EGR schedules
- Modified fuel delivery schedules
- Modified spark timing schedules
- General combustion characteristics of the methanol fuel mixture.

The last four factors above are those most likely to affect emissions from methanol-fueled vehicles.

At the time of the tests the EPA facility was capable of measuring aldehyde emissions, but methanol emissions in the exhaust were not separately measured. As a result, the exhaust methanol values reported[7] and used in the data reduction protocol were inferred from the hydrocarbon analyzer (flame ionization detector - FID) output by (a) knowing the methanol response factor of the analyzer and by (b) making an assumption regarding the relative amounts of non-oxygenated hydrocarbons (NOHC) and unburned methanol in the exhaust. The protocol used by the EPA assumes that the ratio of the NOHC concentration to the methanol concentration in the exhaust of MXX-fueled engines is XX/85 (where XX is the percentage, by volume, of methanol in the blended fuel used). Although this assumption is not universally used, it has a negligible effect on the carbon monoxide and oxides of nitrogen (NOx) values reported. It does, however, impact the values obtained for the organic material hydrocarbon equivalent (OMHCE).

The OMHCE represents the mass of Indolene exhaust hydrocarbons (molecular weight = 13.88 gm/mole) containing the same amount of carbon that exists in the actual mix of non-oxygenated hydrocarbons, unburned methanol, and formaldehyde (HCHO) in the M85 exhaust. The OMHCE will be the same as the HC for an Indolene-fueled engine (which produces essentially no methanol or aldehydes), and the EPA has proposed[8] using the same certification standard (0.41 grams per mile) for the OMHCE produced by methanol-fueled vehicles as it presently uses for the HC produced by Indolene-fueled vehicles.

Table 1 shows results from the EPA tests along with "end-of-the-line" audit test results (random tests of production cars at the end of the production line when cars have no miles accumulated) for the gasoline-fueled production 1987 turbocharged Buick Regal.[7]

Table 1. Emissions Test Results — EPA, Ann Arbor

Vehical ID	FTP results (gm/mile)[a]			
	OMHCE	CO	NOx	HCHO
	Methanol			
9394	0.256	4.95	1.18	0.0334
9398	0.215	2.81	1.12	0.0346
	Indolene			
Audit Data	0.183	2.09	0.18	

[a]Methanol vehicle results are averages for three tests per vehicle.

If the EPA-proposed certification standards were in effect at the time of these tests, both of the methanol cars would exceed the 1.0 gram per mile NOx standard, and vehicle 9394 would fail the 3.4 gram per mile CO standard. A review of the bag-by-bag test results indicates that the CO problem with vehicle 9394 was associated with the warmed-up portions of the FTP cycle (cold stabilized and hot transient phases). Since the car would be expected to operate usually under feedback control ("closed loop" mode) from the oxygen sensor during these portions of the test, and since the methanol-conversion company checked the computer programming after the emission tests and found no problems, it is suspected that the acceleration enrichment schedules used in the software may be responsible for the high CO levels.[7] The high NOx values are almost certainly a result of reduced EGR schedules used in the methanol engine software.

The formaldehyde emissions of about 34 mg/mile are typical of methanol conversions of this type.[7] Values for gasoline vehicles would be expected to be in the 5-10 mg/mile range. Further discussion of emissions test results can be found in Appendix A.

3.2 FLEET UTILIZATION AND FUEL CONSUMPTION

Table 2 summarizes the fleet utilization (mileage accumulation) and fuel consumption results from the ORNL fleet for its first year of operation. Data are shown for total miles driven, average miles per trip,

Table 2. ORNL Fleet Utilization and Fuel Consumption Data First Year — Through December 31, 1988

Vehicle ID	Total miles	Average miles/trip	Fuel economy	
			mpg	km/Gj[a]
		Methanol vehicles		
9390	9,715	12	9.9	231
9392	3,978	7	9.1	212
9394	4,674	8	9.0	210
9396	6,547	12	10.3	240
9398	6,767	18	10.1	236
TOTAL	31,681	11[b]	9.8[b]	228[b]
		Gasoline vehicles		
9391	9,255	13	17.9	237
9393	11,594	17	18.7	247
9395	18,208	21	19.8	261
9397	13,419	19	19.8	261
9399	12,004	22	18.9	249
TOTAL	64,480	18[b]	19.1[b]	253[b]

[a]Based on methanol heating value of 56,560 Btu/gal and gasoline heating value of 115,400 Btu/gal; hence, M85 heating value equals 65,386 Btu/gal.

[b]Based on total quantities, not an average of individual averages.

and average fuel economy for each of the ten cars as well as aggregate totals for the five cars of each type – methanol or gasoline.

Nearly 100,000 miles were accumulated on the ten cars during the period of this report with about two-thirds of the miles being accounted for by the gasoline cars, which were in service for a longer period. Average trip lengths for the methanol cars were shorter probably because the gasoline cars account for the majority of use on out-of-town trips. One of the methanol cars (9390) accounted for nearly one-third of all the miles of that group, and one of the gasoline cars (9395) accounted for nearly one-third of all the gasoline cars' miles. This disparity in use is a problem that requires correction from time-to-time by reassigning the vehicles among the group of participating ORNL divisions.

Energy efficiency (km/Gj) was lower for the methanol group than for the gasoline group, but this likely resulted, at least in part, from the shorter trips experienced by the methanol cars. This difference could possibly disappear if the cars' utilization can be more equally distributed in the future.

3.3 COMPARISON OF MAINTENANCE AND SERVICE

Statistics illustrating the comparison of maintenance and service of the methanol and gasoline vehicles are presented in Table 3.

Table 3. Maintenance Required by ORNL Federal Methanol Fleet Vehicles First Year – Through December 31, 1988

Buick Regals

	Occasions (#)	Frequency (#/1000 mi)	Labor hours	Intensity (hrs/1000 mi)
		Five-car Totals		
All Maintenance				
Methanol	72	2.2	53	1.7
Gasoline	103	1.6	81	1.3
Fuel-Related Maintenance				
Methanol[a]	7	0.2	14	0.4
Gasoline	1	0.02	1	0.02

[a]All are related to early problems with prototype methanol fuel pumps.

Included in this comparison are numbers of occasions of maintenance, frequency of maintenance (occasions per 1000 miles), number of labor hours required for maintenance, and labor intensity (labor hours per 1000 miles). "All Maintenance" includes all occasions for maintenance for which a service work order was written. This would include occasions of routine maintenance such as oil changes and tire maintenance as well as occasions of unusual maintenance, i.e., those occasions that are prompted by complaints or malfunctions. The occasions designated as "Fuel Related" are those which have been identified as being intimately related to the nature of the fuel and/or fuel delivery systems. For methanol cars in general, many of the fuel related occasions result from situations that have been caused by the fuel or the systems incorporated in the conversion to methanol. Similar situations for the gasoline cars have also been designated as fuel related. These delineations are used only in an attempt to show how much of the additional maintenance required by the methanol cars can be traced to the methanol fuel or its systems.

All of the methanol cars' fuel-related maintenance was related to the prototype methanol fuel pumps. The pumps were newly designed and fabricated for methanol compatibility, and there apparently was a fault in attaching a connecting wire in three of the pumps' internals during assembly. This resulted in eventual failure of the pumps (loss of power connection) and required pump replacement. The replacements, along with other occasions of maintenance in trying to determine the nature of the problem, accounted for all of the seven occasions of fuel-related maintenance in the table. As a result, all of the fuel-related maintenance of the methanol cars can arguably be discounted as being exceptional events which are not true indicators of the readiness of methanol vehicle technology for marketing. The single occasion of fuel-related maintenance for the gasoline cars was a fuel injector cleaning that was required because of buildup of deposits on the injector tips.

The overall frequency of maintenance for the methanol cars is reduced to 2.0 occasions per 1000 miles and the labor intensity to 1.2 hours per 1000 miles if one discounts data in the table by the amounts associated with the pump replacements. On the basis of these discounted figures, it can be concluded that there was not any great difference between methanol and gasoline cars in the maintenance required during the first year.

3.4 OIL SAMPLE ANALYSES

Small samples (one or two ounces) of the lubricating oil are drawn from the crankcase of each of the ten cars at approximately 1000 mile intervals. These samples are analyzed for total base number, kinematic viscosity, and concentrations of iron, lead, copper, aluminum, chromium, sodium, and silicon. Generally, a fleet operator uses information from oil sample analyses as a diagnostic tool for implementing necessary preventive or corrective maintenance. In this project, however, the information is not generally used to intervene in the natural processes that are progressing in the engines under study. Only in rare circumstances, such as the revealed need for an air filter change, has the information been used to implement any vehicle service that would not have ordinarily occurred at a given point in time.

No significant abnormal trends have been observed in either the total base number or the kinematic viscosity of the oil of any of the cars for the period of this project. For the ORNL cars, aluminum, chromium, and sodium do not accumulate in any amounts that would warrant further attention here. Silicon enters the oil usually by contamination from dirt in the environment, and data regarding its concentration are not as enlightening as that of other contaminants *vis-à-vis* engine wear. Iron is usually the largest contributor to lubricating oil contamination in both the methanol vehicles and the gasoline vehicles.

Results are presented in Table 4 for accumulation rates of wear metals (iron, lead, and copper) in the lubricating oil. Accumulation rates are found by (a) fitting linear regressions (least squares curve-fits) to data of wear metals concentration as a function of distance since oil change, and (b) determining the slopes (accumulation rates) of the regressions. Figures 2 and 3 show iron and lead concentration data for methanol compared to gasoline cars for the first year. Slopes of the lines fitted to the data are the accumulation rates.

Table 4. Wear Metals Accumulation Rates
First Year - Through December 31, 1988

Buick Regals

Average Wear Metals Accumulated in
Lubricating Oil in Parts per Million
per 1000 Miles of Operation

Wear metal	ppm per 1000 miles	
	Methanol vehicles	Gasoline vehicles
Iron	22	3
Lead	23	3
Copper	7	1

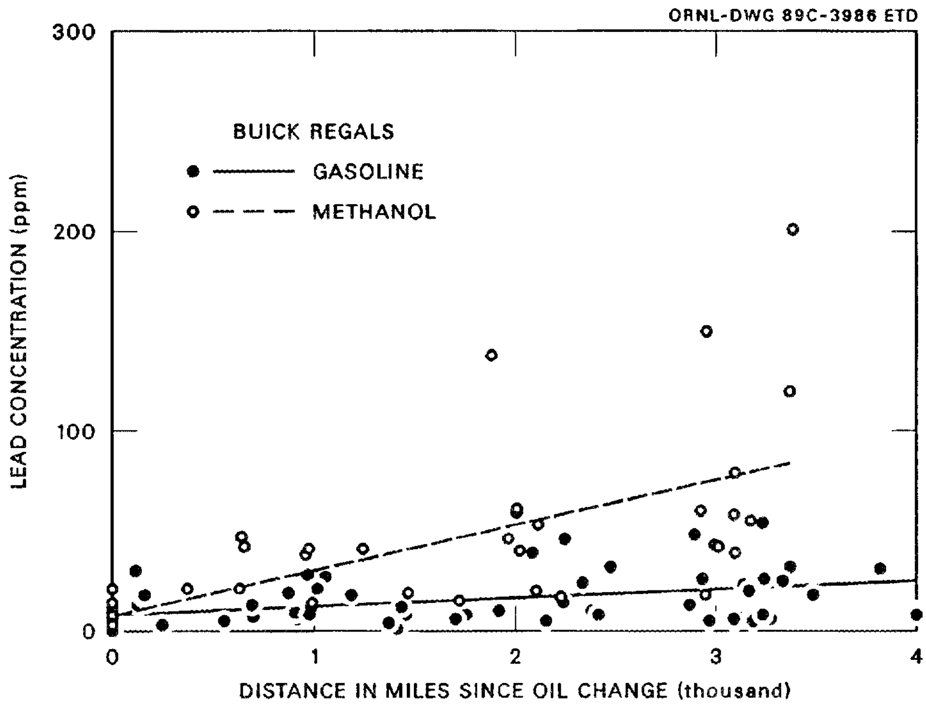

Fig. 2. Iron concentration in lubricating oil.

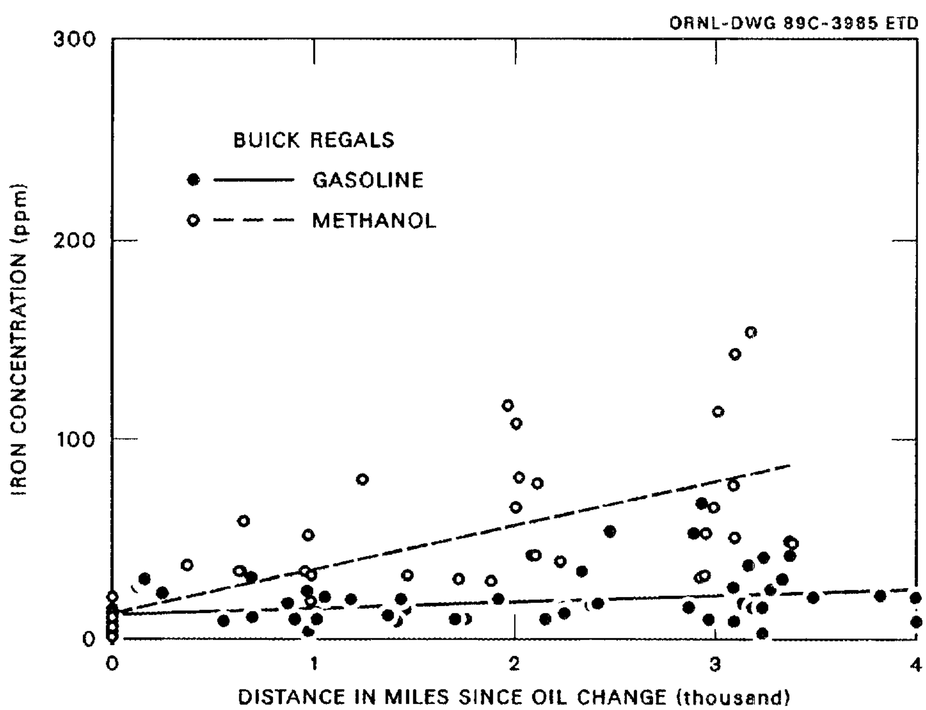

Fig. 3. Lead concentration in lubricating oil.

Both iron and lead are considerably elevated in the oil of methanol cars as compared to gasoline cars but not any more so than in other methanol fleet vehicles at other sites.[9,10] Furthermore, accumulation rates of these metals in the methanol cars is only moderately greater than the rate of the same metals in some of the gasoline cars at another site.[10]

3.5 DRIVERS' RATINGS OF VEHICLE PERFORMANCE

Drivers are asked to evaluate the car's ease of starting and driveability at the end of each trip by making a check mark under either "Good", "Average", or "Poor" on the trip log for both "Ease of Starting" and "Driveability". This simple process yields a profile of the drivers' general impressions of the cars' performance and how their impressions may change over time.

During the year 6530 trip log entries were recorded: 2957 for methanol cars and 3573 for gasoline cars. Approximately 400 persons at ORNL have driven at least one of the cars in the fleet project.

Results of drivers' ratings from the first year are shown in Table 5 in terms both of numbers of responses to the two questions as

Table 5. Responses from ORNL Daily Trip Logs for Ease of Starting and Driveability

First Year - Through December 31, 1988

Buick Regals

	Responses			
	Good	Average	Poor	No response
	Five-car Totals			
Ease of Starting				
		Numbers of Responses		
Methanol	2,070	544	295	48
Gasoline	3,276	201	20	76
		Percent of Total		
Methanol	70	18	10	2
Gasoline	91	6	1	2
Driveability				
		Numbers of Responses		
Methanol	2,724	137	14	82
Gasoline	3,243	201	15	114
		Percent of Total		
Methanol	92	5	0	3
Gasoline	91	6	0	3

well as in percentages. Ratings of driveability are virtually identical between methanol and gasoline cars, and both are rated as "Good" over 90% of the time. Ratings of ease of starting suffered somewhat for the methanol cars with only 70% of the engine starts being rated as "Good" compared with 91% for the gasoline cars. Drivers rated the starting of the methanol cars as poor a sizeable 10% of the time. These poorer ratings help to illuminate the deficiencies of methanol engine systems without additional special engineering for cold weather.

3.6 COLD-WEATHER PERFORMANCE

It is evident from the results of drivers' ratings that the methanol cars suffer from some cold-starting problems, but it is not clear from the global data presented in the previous section just how the ratings are related to weather. To address more rigorously the question of cold-starting, weather, and drivers' acceptance, we have examined the data from the above section in another way. Specifically, the ratings that represented the first trip of each day (first cold-start) have been extracted from the rest of the data and examined separately. This way, in most cases the cars would have had at least a number of hours of "soaking" at the ambient temperature before being started and rated by the driver, although there is no control over the temperature.

Figure 4 shows the average driver rating of ease of starting for the first trip of each day. Numerical values were assigned to the ratings of "Good," "Average," and "Poor" so as to be able to determine an

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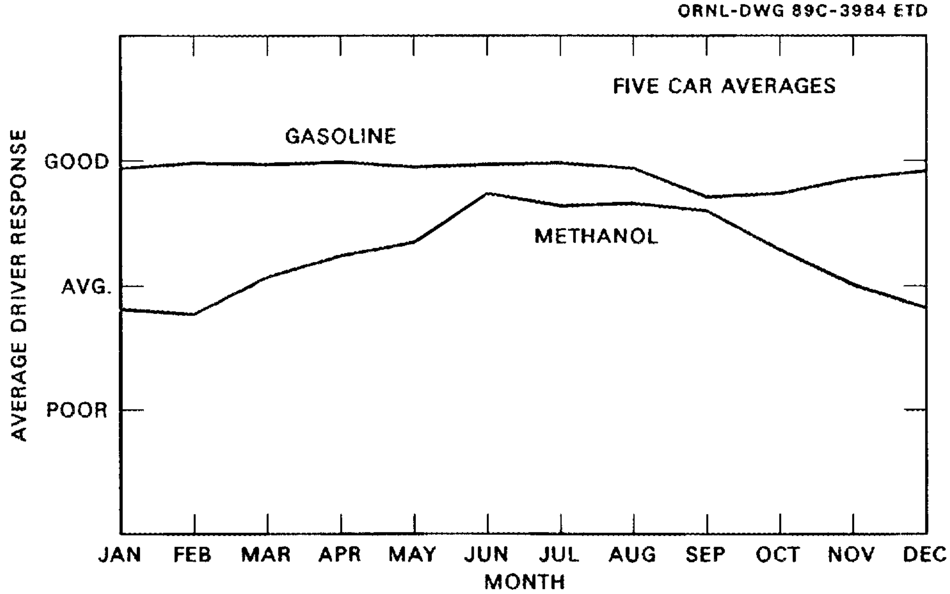

Fig. 4. Average rating of ease of starting – first cold start of each day.

average rating. Ratings of the methanol cars resulted in a very classically shaped plot showing decreasing levels of ratings as the weather became cold. Highest average rating for ease of starting of the methanol cars was in the summer months, lowest in the winter. The ratings for the gasoline cars were very stable with a very high average rating except for an inexplicable slight decline in the early fall.

Qualitative data and reports from car users regarding the ease of starting of the methanol cars during the winter indicates that the starting is reasonably reliable and strong at temperatures down to about 20°F. At temperatures around 15°F starting becomes very difficult and requires lengthy cranking. At temperatures around 10°F or lower, starting is extremely difficult requiring very long cranking times. However, if drivers continued to crank the engines, even at such low temperatures, it was usually possible to succeed in starting the engine. Experiences at such low temperatures were rare, though, during the first year, but there were at least a few reports of drivers failing to start the methanol cars or having great difficulty.

Please note the results in Appendix B of a laboratory analysis of the methanol fuel supply which show that the Reid vapor pressure of the fuel mixture is only about 6 psi. While this could be tailored to be higher with the use of very high vapor pressure gasoline in the 15% portion of the fuel mixture, it is not practical to try to adjust the vapor pressure on the small quantities of fuel (relative to the storage tank size) that are used at ORNL in the winter season. As a result, the fuel mixture had a much lower vapor pressure than is desirable, and this adversely affected the cold-starting performance of the Buicks during the winter season.

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APPENDIX A

Additional Discussion of Emissions Test Results

In order to facilitate future comparisons with emissions results from other testing facilities, the EPA results[7] were recalculated using a different protocol (referred to as the ORNL protocol). This one is identical to that used by the EPA except that it assumes that the ratio of the NOHC concentration (ppm) to the methanol concentration (ppm) in the exhaust is the same as the ratio of the number of moles of gasoline to the number of moles of methanol in the liquid fuel. For M85 this ratio is 0.383, whereas the EPA assumes this ratio is unity.

Using the ORNL protocol and computing the average values for the three tests run on each vehicle yields the following results. (The EPA results are shown also to illustrate that the protocol used has only a limited effect on the OMHCE and methanol values computed.)

FTP Emissions (gm/mile)

Vehicle	9394		9398	
Protocol	ORNL	EPA	ORNL	EPA
MeOH	0.486	0.444	0.418	0.368
CO_2	465	N/A	470	N/A
CO	4.951	4.951	2.809	2.809
NO_x	1.181	1.181	1.117	1.116
OMHCE	0.260	0.256	0.221	0.215
HCHO	0.0334	0.0334	0.0346	0.0346

Clearly, the effect of the protocol is negligible on the CO, NOx, and CO_2 values obtained (not illustrated in CO_2 values shown in this table). Its effect on the OMHCE value is finite but small.

The individual test results are shown below to indicate the degree of repeatability of the results. The ORNL protocol was used to reduce the data, but since the formaldehyde results were not available for the individual tests, the OMHCE values do not include formaldehyde.

Vehicle #9394

Test Number	1	2	3
Odometer (miles)	323	362	401
MeOH	0.398	0.459	0.601
CO_2	465	465	465
CO	3.719	5.129	6.004
NO_x	1.182	1.176	1.186
OMHCE	0.192	0.228	0.315

Vehicle #9398

Test Number	1	2	3
Odometer (miles)	664	704	743
MeOH	0.417	0.427	0.409
CO_2	473	468	470
CO	2.511	3.025	2.891
NO_x	1.104	1.088	1.158
OMHCE	0.203	0.210	0.201

APPENDIX B

Results of laboratory analyses of fuel sample taken from refueling station dispensing pump in July, 1988:

Reid vapor pressure (psi) (by ASTM D-323 dry method)	6.3
Water content (%) (by Karl Fischer method)	0.27
Chlorides (mg/liter) (by ion chromatography)	0.7
Sulfur (mg/liter) (by inductively coupled plasma spectrometry)	0.27
Phosphorus (mg/liter) (by inductively coupled plasma spectrometry)	<0.1

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