EPA-AA-TEB-81-12

Evaporative and Exhaust Emissions of Two Automobiles Fueled with Volatility Adjusted Gasohol

by

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December 1980

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Abstract

This paper presents the objectives and results of a vehicle emission test program conducted by the U. S. Environmental Protection Agency (EPA) in July, 1980. The program was designed to investigate the effects of using various gasohol blends on vehicle evaporative and exhaust emissions. Particular emphasis was directed towards a blended gasohol whose volatility characteristics (ASTM distillation and Reid vapor pressure) were adjusted to match as closely as possible those of a baseline gasoline. Two vehicles received triplicate tests on each of four fuels: 1) a commercial grade unleaded gasoline, 2) a blended gasohol containing 10% ethanol with volatility characteristics similar to Fuel 1, 3) a mixture of 10% ethanol and 90% Fuel 1, and 4) a mixture of 5% ethanol and 95% Fuel 1. The analysis also included a gas chromatograph characterization of the SHED vapors for ethanol concentrations and a comparison of carbon balance fuel economy versus volumetric fuel economy.

Results indicate an overall increase in the total evaporative HC emissions for all three gasohol fuels. Blended gasohol exhibited the lowest increase of 41% while the 10% and 5% gasohol mixtures showed increases of 58% to 62%. Exhaust HC, CO and NOx were reduced with the blended gasohol and 10% gasohol mixture when compared to the baseline gasoline. The 5% gasohol mixture resulted in little or no change. For one test vehicle, the volumetric and carbon balance fuel economy showed a decrease for all three gasohol fuels, while the other vehicle resulted in little or no change. In comparing the two methods of fuel economy measurements (carbon balance and volumetric) the volumetric method was consistently 0.6% higher.

Introduction

As the production capabilities of ethyl alcohol and its use as a fuel additive in the form of "gasohol" increase, continued research of its effect on vehicle emissions is warranted. An earlier study conducted by the U. S. Environmental Protection Agency (1)* showed that the largest detrimental effect on emissions caused by the use of gasohol was in the area of evaporative hydrocarbon (HC) losses. This report stated that an average increase of 49 - 62% could be expected using the current automobile fleet and method of gasohol production. Presently, commercial gasohol is produced by "mixing" 10% (by volume) ethyl alcohol (or ethanol) and 90% finished commercial gasoline. This addition of ethanol drastically alters the volatility of the fuel which results in higher evaporative emissions. One suggested solution to this problem is to "blend" the gasohol at the refinery using heavier base stocks to end up with a gasohol with volatility characteristics (ASTM distillation and Reid vapor pressure) similar to commercial gasoline. As a result of this concept, a test program was designed to investigate the effects of such a gasohol on evaporative and exhaust emissions.

The program consisted of two late model passenger cars that received triplicate evaporative tests using a commercial grade unleaded gasoline, a special blended gasohol with modified volatility characteristics, and two mixed gasohol fuels containing 5% and 10% ethanol. Secondary objectives of the test program included an evaluation of exhaust emissions, a comparison of volumetric and carbon balance fuel economy measurements and gas chromatograph analysis of the SHED vapors for ethanol content.

The purpose of this report is to present the procedures, equipment and results of this investigation.

Test Procedure

The test procedure used in this program consisted mainly of the 1977 Federal Test Procedure (FTP) for evaporative and exhaust emissions (2). Slight deviations from this procedure were introduced to accomodate additional data acquisition and instrument operation. However, these procedures were usually introduced at times during the FTP which allowed completion of the task while still following the FTP time constraints. The deviations from the FTP are listed below and a complete test sequence is given in Appendix A.

- The vehicle charcoal cannister was weighed before and after the Diurnal Heat Build and the Hot Soak evaporative loss tests. This was performed within the FTP time limits.

- A volumetric flowmeter was connected in series between the carburetor and the fuel pump. An electric fuel pump was installed on each vehicle and used to prime the flowmeter and float bowl prior to each driving cycle.

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*Numbers in parentheses designate references at the end of the paper.

- A gas chromotograph was connected thru a sample port to the SHED. A vacuum pump was used to inject the SHED vapor into the column and it is estimated that about .5 liter was removed from the SHED per injection.

- Fuel density was measured immediately prior to each driving cycle by means of an API hydrometer.

- Engine parameters such as the water jacket, engine oil, and carburetor bowl temperatures were recorded during the driving cycle and Hot Soak loss portions of the FTP.

The original test plan called for triplicate tests to be run by each vehicle using each fuel. However, due to void test make-up and a shortage of test fuel, only duplicate tests were run by each vehicle on some of the test fuels.

Test Fuels

The four fuels chosen for the program were tested in the following order:

Fuel 1: A commercial grade unleaded gasoline used as the baseline fuel.

Fuel 2: A blended gasohol containing 10% ethanol and 90% unleaded gasoline having volatility characteristics similar to that of Fuel 1.

Fuel 3: A mixture (by volume) of 10% ethanol and 90% Fuel 1.

Fuel 4: A mixture (by volume) of 5% ethanol and 95% Fuel 1.

The test fuels were selected to investigate two suggested methods of reducing evaporative hydrocarbon emissions from gasohol fueled vehicles. The first method is that of blending the gasohol to have lower volatility by using heavier base stocks and adding ethanol. The second method was to reduce the concentration of the ethanol to 5%.

The volatility match between Fuel 1 and Fuel 2 turned out to be very difficult to obtain within the original specifications of identical Reid vapor pressure (RVP) and ASTM distillation curves within ±5°F of each other. The fuel finally purchased from the Amoco Oil Company in Naperville, Illinois was within 0.1 psi RVP and ±20°F ASTM distillation.

Fuel 3 is a mixture of 10% ethanol and 90% Fuel 1. This fuel represents a typical gasohol currently on the commercial market.

Fuel 4 is also a mixture with 5% ethanol and 95% Fuel 1. This fuel was used to investigate the effects of a lower concentration of ethanol.

The fuel characteristics for all four fuels are shown in Table 1 and a comparison of the ASTM distillation data is displayed in Figure 1. The test fuels were stored in sealed drums until testing started on that particular fuel. They were then tranferred to a vented, chilled fuel cart and kept at 48 - 52°F.

The fuels were tested in the specified numerical order except that the baseline fuel (Fuel 1) was repeated at the end of the test sequence to confirm that the baseline results did not shift.

Table 1
Fuel Inspection Data

ITEM	Fuel 1 Baseline Gasoline	Fuel 2 Blended Gasohol	Fuel 3 10% Gasohol	Fuel 4 5% Gasohol
1. API Gravity	54.9	49.2	54.2	54.6
2. Sp. Gravity	.759	.783	.762	.760
3. R.O.N.	95.2	99.4	-	-
4. M.O.N.	84.3	87.2	-	-
5. RVP, PSI	9.3	9.4	10.2	10.4
6. ASTM Dist.				
IBP	95°F	102°F	92°F	97°F
10%	120	128	118	116
20%	143	147	133	129
30%	173	160	146	146
40%	208	194	156	186
50%	240	258	210	226
60%	267	278	251	257
70%	294	301	281	286
80%	320	321	311	314
90%	354	350	345	348
EP	432	434	425	424
Analysis Performed: by	Amoco Oil Co.	Amoco Oil Co.	Ethyl Corp.	Ethyl Corp.

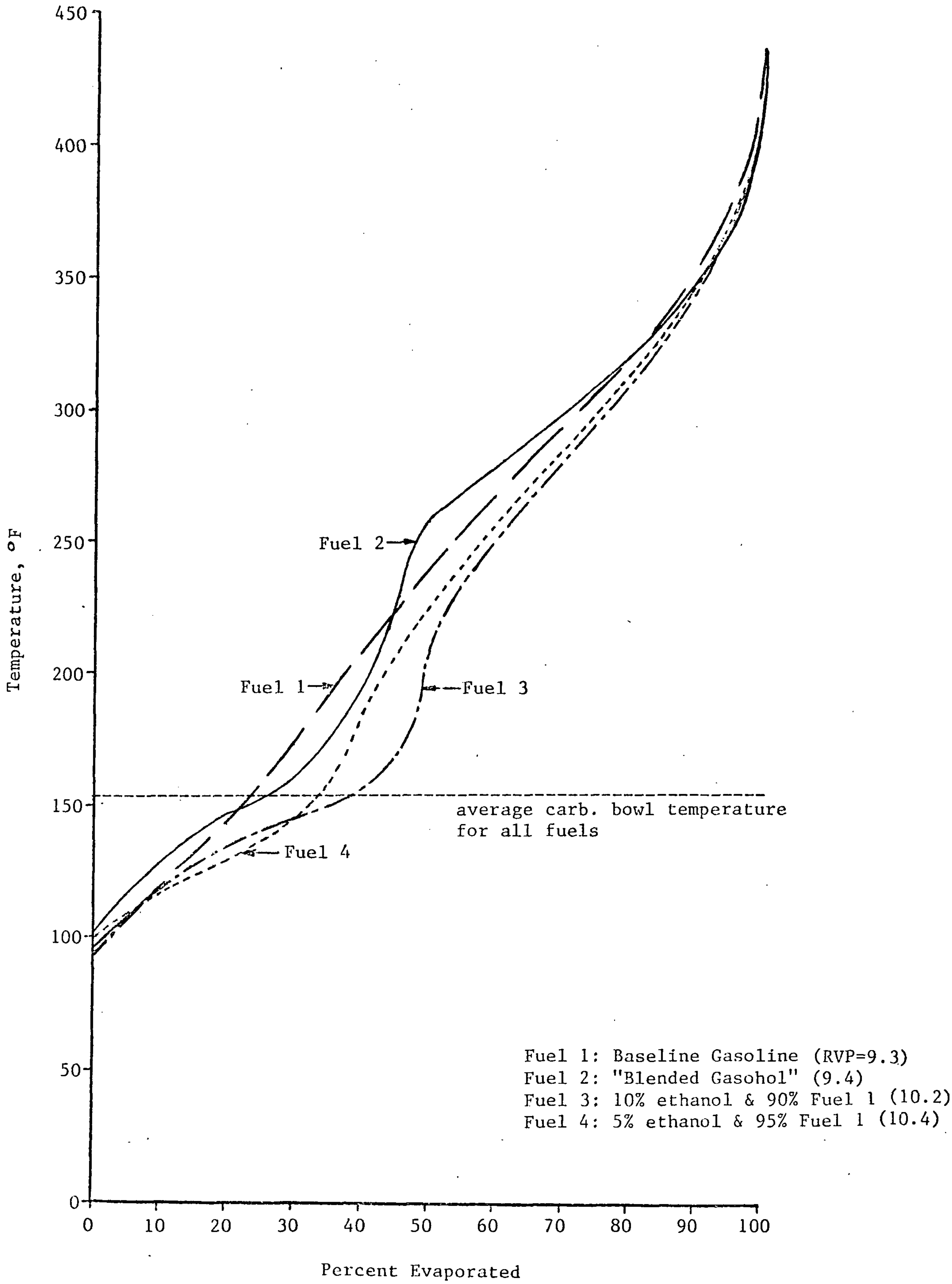


Fig. 1 - ASTM Distillations for Test Fuels

Test Vehicles

The two test vehicles used were a 1979 Buick Regal and a 1979 Chrysler LeBaron. Vehicle specifications for these cars can be found in Appendix B.

Prior to testing, the vehicles were inspected and adjusted to meet manufacturer's specifications and the mechanical fuel pump was bypassed with an electical pump. This pump was necessary to prime the volumetric flowmeter and float bowl prior to each test.

Instrumentation of the vehicles included bare-bead, type J thermocouples located in the fuel tank, carburetor bowl, engine oil pan, and in the engine water jacket. The engine parameters were measured as indicators of test condition and load repeatability and the fuel parameters were correlated back to the evaporative emission results.

Fuel flow was also measured volumetrically using a flowmeter which was placed between the fuel pump and the carburetor. The same flowmeter was used for both cars and was connected and primed before each test. Fuel density was also measured at this time using an API hydrometer.

Gas Chromatograph Analysis

The gas chromatograph analysis of the SHED vapors was used to quantitatively determine the concentration ot ethanol vapors in the evaporative emissions. The gas chromatograph (G.C.) used was a Perkin-Elmer Model 3920 witn dual FID detectors. The column consisted of ten feet of 1/8 inch O.D. tubing packed with tris (cyano ethoxy) propane. The column temperature was kept at 50°C which resulted in the ethanol peaking at 15 minutes. A sample pump (from a Philco Ford CVS) was used to inject the vapor into the column and the G.C. response was traced on a strip chart recorder. The peak widths were assumed to be relatively constant and no effort was made to integrate the peak areas.

The G.C. was calibrated prior to the program using the following procedure: After stabilizing the instrument at the indicated temperature and purging the column (for three days) a small petri dish containing anhydrous ethanol was left partially uncovered on a balance in the SHED. Immediately after the SHED was sealed, an initial sample was injected into the G.C. and the digital balance reading recorded. Then, at a frequency determined by the G.C. sampling rate, additional samples were injected and weights recorded as the ethanol slowly evaporated. This procedure was repeated once and the data reduced to a grams ETOH versus G.C. response curve. A linear regression revealed a linear relationship (coefficient of determination, R^2 = .9939) and a SHED volume correction factor was introduced to account for a vehicle in the SHED. However, no corrections were made for barometric pressure or ambient temperature variations.

Test Results

EVAPORATIVE EMISSION RESULTS - The evaporative HC emission test results for each vehicle are presented in Table 2. The average results for the program are presented in Table 4 and displayed graphically in Figure 2. These results demonstrate several noticeable trends.

Considering the blended gasohol (Fuel 2) first, the total vapor generated (vehicle canister weight gain plus SHED evaporative results) using this fuel was 3% less than the total vapor generated by the baseline gasoline which would be expected because of the lower front end volatility of the blended fuel (see Table 4). However, the total SHED test emissions were 41% higher than the baseline gasoline. Breaking this down into the Diurnal Breathing Loss (DBL) and the Hot Soak Loss (HSL) portions of the SHED test, shows that most of the evaporative emissions increase came from the HSL test where a 21% increase in the vapor generated was observed. This can be explained by examining the distillation curves for both these fuels and noting that the highest achieved carburetor bowl temperatures during the HSL tests were above 150°F where the blended gasohol is more volatile than the baseline fuel (all the gasohol fuels had carburetor bowl temperatures of about 153°F and the baseline gasoline had a carburetor bowl temperature of about 156°F).

The total vapor generated during the DBL test dropped by about 13% when using blended gasohol, however the evaporative losses rose by 6%. This indicates an effect on the trapping efficiency of the canister charcoal by the alcohol. This efficiency loss was 1% (not statistically significant) for the LeBaron and 4% for the Regal. It is hard to determine if the alcohol is being preferentially absorbed by the charcoal since the gas chromatograph data varied widely for each test vehicle. The LeBaron's ethanol emissions accounted for 12% of the total losses when using blended gasohol, while the Regal's ethanol loss accounted for only 2%. The gas chromatograph data is presented in Appendix C.

In comparing the 10% ethanol - 90% baseline fuel mixture (Fuel 3) to the baseline fuel, a 24% increase in the total vapor generated and a 58% increase in the total evaporative losses can be seen (see Table 4). Again, the increased volatility of the mixture is the primary reason for these increases, but compounding this is the trapping efficiency decrease (about 3% average) of the charcoal canister. The fuel mixture containing 5% ethanol and 95% baseline gasoline (Fuel 4) exhibited similar evaporative emission results as did Fuel 3. The total vapor generated rose to 25% compared to the baseline fuel results, and the total evaporative losses rose 62%. This fuel had the highest Reid vapor pressure and low end volatility which caused the Diurnal losses to increase 106%. The Hot Soak losses rose 20% which was the lowest of the three gasohol fuels tested.

EXHAUST EMISSION RESULTS - The exhaust emission results for each vehicle are presented in Table 3. The average results for the program are presented in Table 5 and displayed graphically in Figure 3.

In comparing the blended gasohol and the 10% gasohol mixture to the baseline gasoline we find a significant decrease in the exhaust HC, CO and NOx emissions. HC decreased by 8% for the blended gasohol and 23% for the 10% gasohol mixture, while CO decreased 35% and 40% respectively. NOx emissions were reduced 22% for the blended gasohol and 3% for the 10%

gasohol mixture. This can be explained by noting the leaning effect the ethanol has on the air/fuel ratios. NOx emissions may have been affected by cylinder temperature variations due to the presence of ethanol. However, for the 5% gasohol mixture, the leaning effect is not as apparent since the exhaust emission results closely resemble those of the baseline fuel.

FUEL ECONOMY RESULTS - For this test program the EPA city fuel economy was measured by both the carbon balance method and using a volumetric flowmeter. However, due to a lack of availability of the flowmeter Fuel 4 was not measured volumetrically. The average results for the program are presented in Table 5 and displayed graphically in Figure 3. Figure 4 provides a comparison of the carbon balance method versus the volumetric measurement.

For all the gasohol fuels tested, a slight decrease in the average fuel economy was observed for both the carbon balance method and the volumetric measurement when compared to the baseline gasoline (one vehicle showed a decrease while the other vehicle showed little or no change). The 10% gasohol mixture produced the largest decrease of 2%. These results are expected since the energy content of gasohol is known to be below that of gasoline. However, other sources have shown that ethanol burns more efficiently in the combustion chamber thereby minimizing the effect of a lower energy density.

In comparing the volumetric measurement to the carbon balance method, the volumetric measurement was consistently 0.6% higher. A summary of the calculations used for the carbon balance method is given in Appendix D.

Table 2 - Evaporative HC Emission Results for Individual Vehicles

1979 LeBaron

Fuel	N		SHED Results (gm)			Vehicle Canister Weight Gains (gm)		Total Vapor Generated (gm)		
			Diurnal	Hot Soak	Total	Diurnal	Hot Soak	Diurnal	Hot Soak	Total
Fuel 1	5	mean	1.34	2.46	3.80	24.50	9.58	25.84	12.04	37.88
		s.dev	0.25	0.20	0.16	1.84	0.54	1.62	0.66	2.09
Fuel 2	3	mean	1.50	3.67	5.17	20.80	9.67	22.30	13.34	35.64
		s.dev	0.04	0.35	0.36	1.73	0.50	1.71	0.75	2.02
		% ch	11.9	49.2	36.1	-15.1	0.9	-13.7	10.8	-5.9
Fuel 3	3	mean	1.81	3.36	5.17	25.03	16.17	26.84	19.53	46.37
		s.dev	0.09	0.17	0.08	1.69	3.34	1.67	3.18	4.08
		% ch	35.1	36.6	36.1	2.2	68.8	3.9	62.2	22.4
Fuel 4	2	mean	2.64	3.33	5.97	30.20	12.55	32.84	15.88	48.72
		s.dev	0.66	0.40	0.27	0.99	0.07	0.33	0.47	0.79
		% ch	97.0	35.4	57.1	23.3	31.0	27.1	31.9	28.6

1979 Regal

Fuel	N		SHED Results (gm)			Vehicle Canister Weight Gains (gm)		Total Vapor Generated (gm)		
			Diurnal	Hot Soak	Total	Diurnal	Hot Soak	Diurnal	Hot Soak	Total
Fuel 1	5	mean	3.34	2.45	5.79	21.84	7.70	25.18	10.15	35.33
		s.dev	0.79	0.74	0.71	0.53	0.75	0.48	0.38	0.56
Fuel 2	3	mean	3.44	4.95	8.39	18.47	8.67	21.91	13.62	35.53
		s.dev	0.65	0.35	0.95	0.84	0.23	1.39	0.54	1.58
		% ch	3.0	102.0	44.9	-15.4	12.6	-13.0	34.2	0.6
Fuel 3	3	mean	5.78	4.17	9.95	22.43	12.20	28.21	16.37	44.58
		s.dev	0.80	0.14	0.92	0.96	2.21	0.24	0.18	0.91
		% ch	73.1	70.2	71.8	2.7	58.4	12.0	61.3	26.2
Fuel 4	2	mean	6.97	2.60	9.57	21.85	11.70	28.82	14.30	43.12
		s.dev	1.33	0.04	1.29	2.05	0.14	0.72	0.18	0.91
		% ch	108.7	6.1	65.3	0.04	51.9	14.5	40.9	22.0

Notes:
1. HC results are not corrected for the ethanol response of the FID.
2. % ch is referenced to Fuel 1.
3. Total vapor generated = SHED results + vehicle canister weight gain.

Table 3 - Exhaust Emissions and Fuel Economy Results for Individual Vehicles

1979 LeBaron

Fuel	N		HC	CO	NOx	CO_2	MPG C.B. F.E.	MPG Vol. F.E.
			FTP Results (gm/mi)					
Fuel 1	4	mean	0.70	13.55	1.82	533.	16.4	16.4
		s.dev	0.02	0.58	0.12	0.82	0.05	0.07
Fuel 2	3	mean	0.54	7.67	1.65	535.	16.6	16.5
		s.dev	0.05	0.86	0.29	2.08	0.10	0.06
		% ch	-22.9	-43.4	-9.3	0.4	1.2	0.6
Fuel 3	3	mean	0.55	8.13	1.84	523.	16.4	16.4
		s.dev	0.03	0.23	0.02	3.21	0.12	0.15
		% ch	-21.4	-40.0	1.1	-1.9	0.0	0.0
Fuel 4	1	mean	0.68	12.10	1.88	521.	16.5	-
		% ch	-2.9	-10.7	3.3	-2.3	0.6	-

1979 Regal

Fuel	N		HC	CO	NOx	CO_2	MPG C.B. F.E.	MPG Vol. F.E.
			FTP Results (gm/mi)					
Fuel 1	4	mean	1.02	7.33	3.01	469.	18.9	19.1
		s.dev	0.16	0.71	0.13	7.04	0.24	0.15
Fuel 2	3	mean	1.04	5.97	2.13	483.	18.4	18.6
		s.dev	0.06	0.67	0.51	2.65	0.06	0.07
		% ch	2.0	-18.6	-29.2	3.0	-2.6	-2.6
Fuel 3	3	mean	0.77	4.50	2.86	472.	18.3	18.5
		s.dev	0.02	0.10	0.11	6.24	0.25	0.10
		% ch	-24.5	-38.6	-5.0	0.6	-3.2	-3.1
Fuel 4	1	mean	1.08	7.90	3.06	474.	18.3	-
		% ch	5.9	7.8	1.7	1.1	-3.2	-

Notes:
1. HC results are not corrected for the ethanol response of the FID.
2. % ch is referenced to Fuel 1.
3. C.B.F.E. = Carbon Balance Fuel Economy.
   Vol. F.E. = Volumetric Fuel Economy.

Table 4 - Average Evaporative HC Emission Results for Test Program

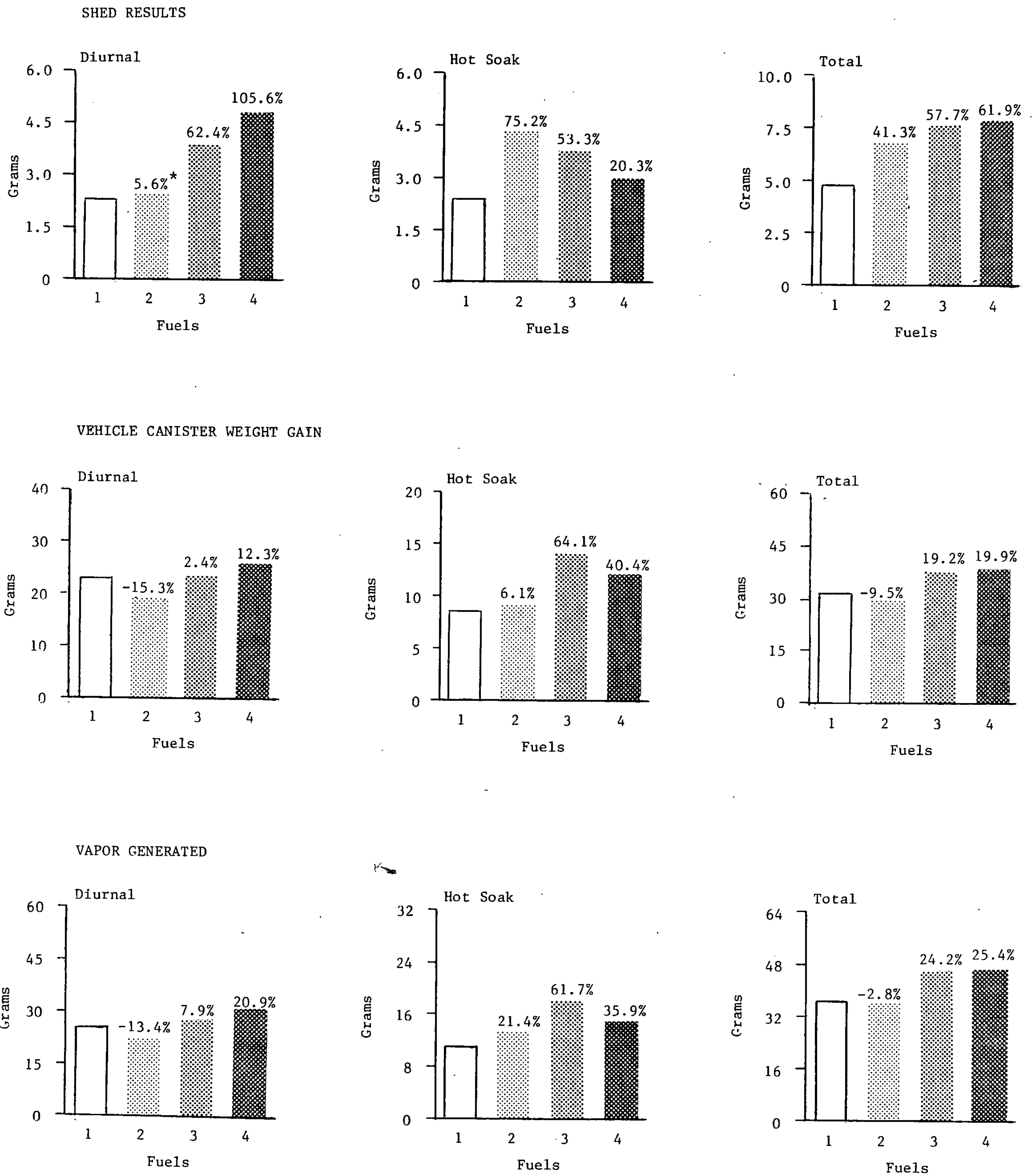
Fuel	N		Shed Results (gm) Diurnal	Shed Results (gm) Hot Soak	Shed Results (gm) Total	Vehicle Canister Weight Gains (gm) Diurnal	Vehicle Canister Weight Gains (gm) Hot Soak	Vehicle Canister Weight Gains (gm) Total	Total Vapor Generated (gm) Diurnal	Total Vapor Generated (gm) Hot Soak	Total Vapor Generated (gm) Total
Fuel 1	10	mean	2.34	2.46	4.80	23.17	8.64	31.81	25.51	11.10	36.61
Fuel 2	6	mean	2.47	4.31	6.78	19.63	9.17	28.80	22.10	13.48	35.58
		% ch.	5.6	75.2	41.3	-15.3	6.1	-9.5	-13.4	21.4	-2.8
Fuel 3	6	mean	3.80	3.77	7.57	23.73	14.18	37.91	27.53	17.95	45.48
		% ch.	62.4	53.3	57.7	2.4	64.1	19.2	7.9	61.7	24.2
Fuel 4	4	mean	4.81	2.96	7.77	26.02	12.13	38.15	30.83	15.09	45.92
		% ch.	105.6	20.3	61.9	12.3	40.4	19.9	20.9	35.9	25.4

Notes:
1. HC results are not corrected for the ethanol response of the FID.
2. % ch is referenced to Fuel 1.
3. Total vapor generated = SHED results + vehicle canister weight gain

Table 5 - Average Exhaust Emissions and Fuel Economy Results for Test Program

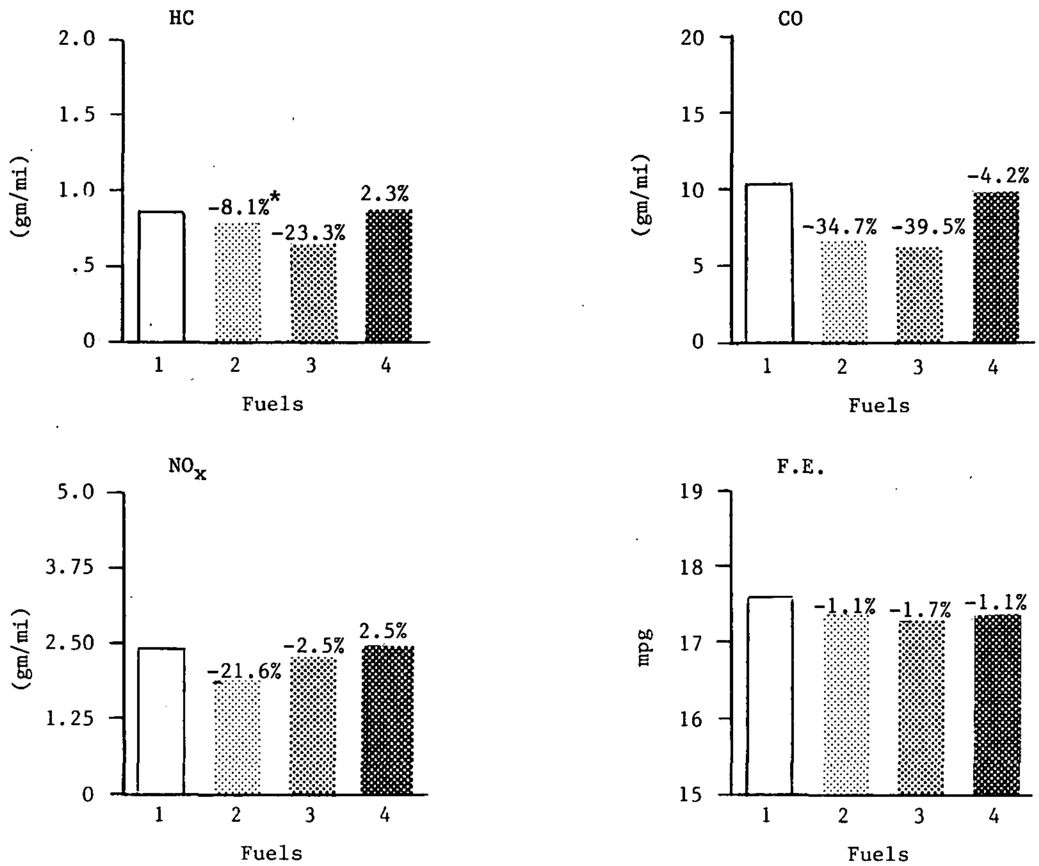
Fuel	N		FTP Results (gm/mi) HC	CO	NOx	CO_2	MPG C.B. F.E.	Vol. F.E.
Fuel 1	8	mean	.86	10.44	2.41	501.	17.6	17.7
Fuel 2	6	mean	.79	6.82	1.89	509.	17.4	17.5
		% ch	-8.1	-34.7	-21.6	1.6	-1.1	-1.1
Fuel 3	6	mean	.66	6.32	2.35	497.	17.3	17.4
		% ch	-23.3	-39.5	-2.5	-.8	-1.7	-1.7
Fuel 4	2	mean	.88	10.00	2.47	498.	17.4	-
		% ch	2.3	-4.2	2.5	-.6	-1.1	-

Notes:
1. HC results are not corrected for the ethanol response of the FID.
2. % ch is referenced to Fuel 1.
3. C.B.F.E. = Carbon Balance Fuel Economy.
   Vol. F.E. = Volumetric Fuel Economy.



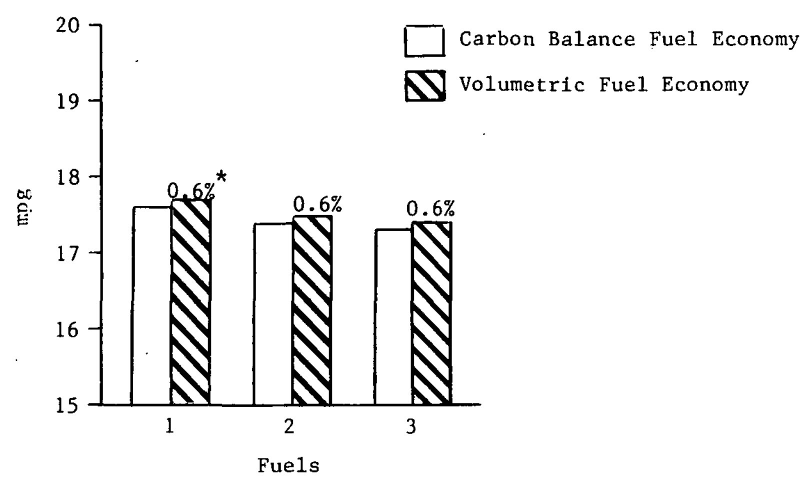
* percent change from Fuel 1

Fig. 2 - Evaporative HC emission results (average of 2 vehicles)



* percent change from Fuel 1

Fig. 3 - FTP exhaust emissions and fuel economy results (average of 2 vehicles)



* percent change from carbon balance method

Fig. 4 - Carbon balance versus volumetric fuel economy

Conclusions

Based on the findings of this test program several conclusions can be made concerning the emissions effect of "blended" gasohol and "mixed" gasohol fuels:

1) Blended gasohol exhibited approximately 41% greater evaporative HC emission losses than the base fuel.

2) The presence of ethyl alcohol caused about a 1-3% loss in the trapping efficiency of the canister.

3) Reducing the concentration of ethanol from 10% to 5% does not reduce evaporative HC emissions. The two mixed gasohol fuels (10% gasohol mixture and 5% gasohol mixture) increased evaporative HC emissions by an average of 60%.

4) The blended gasohol decreased exhaust HC by 8% and the 10% gasohol mixture decreased exhaust HC by 23%. The 5% gasohol mixture increased exhaust HC by 2%.

5) Exhaust CO decreased 4-40% with all the gasohol fuels.

6) NOx emissions decreased 22% with the blended gasohol and 3% with the 10% gasohol mixture. NOx emissions increased 3% with the 5% gasohol mixture.

7) Fuel economy (by carbon balance and volumetrically) decreased about 1-2% with all the gasohol fuels. (One test vehicle showed a decrease while the other vehicle showed little or no change).

8) The volumetric fuel economy measurement was 0.6% higher than the carbon balance method.

References

1. Richard Lawrence, "Gasohol Test Program," EPA Report 79-4, December, 1978.

2. Federal Register, Vol. 41, No. 164, August 23, 1976

3. California Air Resources Board, "Testing of Three Caltrans Gasohol Fueled Vehicles," Project 2F80E2, May, 1980.

Appendix A

Test Procedure

Gasohol Test Sequence

1. Drain and refuel to 20% tank capacity
2. Run 1 LA-4 driving cycle
3. Hot soak one hour
4. Drain and refuel to 40% tank capacity
5. Run 1 LA-4 driving cycle
6. Soak 12 - 24 hours at 68 - 75°F ambient temperature
7. Run 1 FTP with SHED:

    a. Diurnal Heat Build:

        - drain and refuel to 40% tank capacity (leave fuel cap off)
        - move vehicle to SHED
        - weigh vehicle canister and check canister lines
        - move vehicle into SHED
        - at 58°F fuel temperature, install fuel cap and seal enclosure doors
        - take gas chromatograph sample (at 60°F)
        - perform one hour diurnal heat build (at 60°F)
        - take gas chromatograph sample (at 84°F)
        - immediately weigh vehicle canister and check canister lines

    b. Run 3-bag FTP emissions test within 60 minutes of end of diurnal test

    c. Hot Soak:

        - immediately after 3-bag emissions test, move vehicle to SHED
        - weigh vehicle canister and check canister lines
        - move vehicle into SHED and seal enclosure doors
        - take gas chromatograph sample and perform one hour soak test
        - after one hour, take gas chromatograph sample
        - immediately weigh vehicle canister and check canister lines

8. Precondition for the next test

    a. If using the same fuel, go to step 5
    b. If switching fuels, go to step 1

Appendix B

Test Vehicle Specifications

VEHICLE SPECIFICATION REPORT -(LD TESTING)- DATE OF ENTRY : 6/25/80

VEHICLE SPECIFICATIONS

MANUFACTURER	VEHICLE ID	/ VER	REPRESENTED CARLINE	MODEL CODE	DRIVE CODE	SOURCE
CHRYSLER	VMX-253	0		SEDAN	REAR DRIVE STR. LEFT	OTHER

VEHICLE TYPE	ACTUAL VEHICLE MODEL	MODEL YEAR	ACTIVE YEAR	DRIVE AXL WTS FULL TANK	DRIVE AXL WTS EMPTY TANK	CURB WEIGHT	INRTIA CLASS	EQUIV. TEST WEIGHT	O/D CODE	ACTUAL DYNO HP	RUNNING CHG NUMBER
NON-CER	LEBARON	79	79				4000P	4000P		11.9	

PRIMARY DURABILITY VEHICLE ID OR ASSIGNED DF		ALT. MANUFACTURER

TIRE - SPECIFICATIONS

TIRE & RIM SIZES	MFR	CONSTR	SWL N	SWL M	BLT N	BLT M	PSI FT	PSI RR

ENGINE SPECIFICATIONS

DISPLACEMENT	BORE	STROKE	RATED HP	ENGINE TYPE	ENGINE CONFIGURATION	NO. CYL.	NO. CARBS	TOTAL # BBLS	FUEL SYSTEM MFR/MODEL	FUEL INJCT?	TURBO?	COMP. RATIO	COAST-DOWN TM
318. E	.	.		OTTO SPARK	V-BLOCK	8	1	2		NO	NO	.	

IGNITION TIMING 1	IGNITION TIMING 2	TIM. TOL.	TIMING RPM	RPM TOL.	TIM. GEAR	% CO LEFT	% CO RIGHT	% CO COMB.	CO TOL.	IDLE RPM	IDLE TOL.	IDLE GEAR	ENGINE FAMILY	ENGINE CODE
16B			730											

DRIVE TRAIN AND CONTROL SYSTEM SPECIFICATIONS

AXLE RATIO	N/V RATIO	ODOMETER	A/C INSTALLED	EXHAUST TYPE	CRANKCASE SYSTEM	TRANSMISSION CONFIGURATION	TRANSMISSION CODE	EVAPORATION SYSTEM	FUEL TYPE
.	.		YES	SINGLE RIGHT REAR	CLOSED	A-3		CANISTER	UNLEADED (AT EPA-IND HO)

MAIN-TANK CAPACITY	MAIN-TANK VOLUME	AUX.-TANK CAPACITY	AUX.-TANK VOLUME	SHIFT SPEED	EVAPORATIVE EMISSION FAMILY	EVAPORATIVE EMISSION CODE	SALES CLASS
18. G	7.2G						

CONTROL SYSTEM TYPES

EXHAUST RECYCLE	OXIDATION CATALYST	OTHER		

VEHICLE SPECIFICATION COMMENTS

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VEHICLE SPECIFICATION REPORT -(LD TESTING)- DATE OF ENTRY : 6/26/80

VEHICLE SPECIFICATIONS

MANUFACTURER	VEHICLE ID	/ VER	REPRESENTED CARLINE	MODEL CODE	DRIVE CODE	SOURCE
GENERAL MOTORS	VLC-597	0		SEDAN	REAR DRIVE STR. LEFT	OTHER

VEHICLE TYPE	ACTUAL VEHICLE MODEL	MODEL YEAR	ACTIVE YEAR	DRIVE AXL WTS FULL TANK	DRIVE AXL WTS EMPTY TANK	CURB WEIGHT	INRTIA CLASS	EQUIV. TEST WEIGHT	O/D CODE	ACTUAL DYNO HP	RUNNING CHG NUMBER
NON-CER	REGAL	79	79				3500P	3750P		11.2	

PRIMARY DURABILITY VEHICLE ID OR ASSIGNED DF		ALT. MANUFACTURER

TIRE - SPECIFICATIONS

TIRE & RIM SIZES	MFR	CONSTR	SWL N	SWL M	BLT N	BLT M	PSI FT	PSI RR

ENGINE SPECIFICATIONS

DISPLACEMENT	BORE	STROKE	RATED HP	ENGINE TYPE	ENGINE CONFIGURATION	NO. CYL.	NO. CARBS	TOTAL # BBLS	FUEL SYSTEM MFR/MODEL	FUEL INJCT?	TURBO?	COMP. RATIO	COAST-DOWN TM
305. E	.	.		OTTO SPARK	V-BLOCK	8	1	2		NO	NO	.	

IGNITION TIMING 1	IGNITION TIMING 2	TIM. TOL.	TIMING RPM	RPM TOL.	TIM. GEAR	% CO LEFT	% CO RIGHT	% CO COMB.	CO TOL.	IDLE RPM	IDLE TOL.	IDLE GEAR	ENGINE FAMILY	ENGINE CODE
12B			650											

DRIVE TRAIN AND CONTROL SYSTEM SPECIFICATIONS

AXLE RATIO	N/V RATIO	ODOMETER	A/C INSTALLED	EXHAUST TYPE	CRANKCASE SYSTEM	TRANSMISSION CONFIGURATION	TRANSMISSION CODE	EVAPORATION SYSTEM	FUEL TYPE
.	.		YES	SINGLE RIGHT REAR	CLOSED	A-3		CANISTER	UNLEADED (AT EPA-IND HO)

MAIN-TANK CAPACITY	MAIN-TANK VOLUME	AUX.-TANK CAPACITY	AUX.-TANK VOLUME	SHIFT SPEED	EVAPORATIVE EMISSION FAMILY	EVAPORATIVE EMISSION CODE	SALES CLASS
18.0G	7.2G						

CONTROL SYSTEM TYPES

EXHAUST RECYCLE	OXIDATION CATALYST	OTHER		

VEHICLE SPECIFICATION COMMENTS

BUICK REGAL USED FOR GASOHOL STUDY

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Appendix C

Gas Chromatograph Raw Data

Gas Chromatograph Raw Data of Ethanol Vapors

Vehicle		BDB		ADB		BHS		AHS		DDB	DHS	Total
Test		def.	gms.	def.	gms.	def.	gms.	def.	gms.	gms.	gms.	Test
Regal	Blended #1	2.2	.055	7.8	.213	5.8	.157	9.1	.249	.158	.092	.250
	Blended #2	-	-	-	-	-	-	-	-	-	-	--
	Blended #3	2.0	.050	4.0	.106	2.8	.072	5.6	.151	.056	.079	.135
	Mean									.107	.086	.193
	S.D.									.072	.009	.081
	10% #1	4.5	.120	5.8	.157	3.7	.097	6.1	.165	.037	.068	1.05
	10% #2	0.1	0.0	1.9	.047	0.1	0.0	0.9	.019	.047	.019	.066
	10% #3	0.6	.010	2.0	.050	0.1	0.0	5.0	.134	.040	.040	.080
	Mean									.041	.042	.084
	S.D.									.005	-	.020
	5% #1	0.2	0.0	1.3	.030	0.0	0.0	1.9	.047	.030	.047	.077
LeBaron	Blended #1	-	-	-	-	0.2	0.0	4.2	.111	-	.111	--
	Blended #2	1.6	0.38	16.8	.466	3.4	.089	15.1	.418	.428	.329	.757
	Blended #3	2.0	.050	10.7	.295	5.4	.145	13.7	.379	.245	.234	.479
	Mean									.337	.225	.618
	S.D.									-	.109	.197
	10% #1	0.7	.013	12.0	.331	8.7	.221	14.1	.390	.318	.169	.487
	10% #2	0.2	.0	1.4	.033	0.0	0.0	4.1	.109	.033	.109	.142
	10% #3	0.3	.002	2.2	.055	0.1	0.0	4.9	.131	.053	.131	.184
	Mean									.135	.136	.271
	S.D.									-	.030	--
	5% #1	0.6	0.10	1.8	.044	0.0	0.0	4.9	.131	.034	.131	.165

Notes: 1. BDB = before diurnal test
ADB = after diurnal test
BHS = before hot soak test
AHS = after hot soak test
DDB = Δ diurnal test (ADB - BDB)
DHS = Δ hot soak (AHS - BHS)

Appendix D

Carbon Balance Fuel Economy Calculations

Carbon Balance Fuel Economy Calculations

The carbon balance formula is used to calculate the fuel economy of a vehicle from the exhaust emission data gathered during the 1975 Federal Test Procedure. This equation is in the following general form:

$$MPG = \frac{\text{grams of carbon/gallon of fuel}}{\text{grams of carbon in exhaust/mile}}$$

From this general formula, the equation for calculating the fuel economy of a vehicle using indolene fuel is:

$$MPG = \frac{0.866\ (2798)}{0.866[E_{HC}] + .429[E_{CO}] + .273[E_{CO_2}]}$$

where: 2798 = density of indolene fuel (g/gal)
E = exhaust emissions (g/mi)
.866, .429 and .273 are the carbon weight fraction of HC, CO and CO_2 respectively

Since the fuel properties of the baseline gasoline and gasohol fuels used in this test program differ from indolene, the carbon balance equation had to be modified to compensate for these differences. As a result, the carbon balance formula was reduced to the following form:

$$MPG = \frac{D(W)}{F[E_{HC}] + .429[E_{CO}] + .273[E_{CO_2}]}$$

where: D = fuel density (g/gal)
W = carbon weight fraction of fuel
F = carbon weight fraction of exhaust HC
E = exhaust emissions (g/mi)

The values of D, W and F for the four fuels tested in this program are tabulated below:

	D	W	F	D(W)
Fuel 1	2867.12	0.8702	0.8702	2494.97
Fuel 2	2957.78	0.8400	0.8764	2484.54
Fuel 3	2878.45	0.8341	0.8702	2400.92
Fuel 4	2870.90	0.8527	0.8702	2448.02

The following section provides a brief summary of the equations or methods used in determining the above values of D, W, and F for the various fuels. It should be noted that the carbon weight fractions of the base gasoline (Fuel 1) and the blended gasohol (Fuel 2) were supplied by Amoco Oil Company. As a result, the equation to determine the carbon weight fraction of the fuel was only applied to the 10% and 5% mixtures of gasohol (Fuel 3 and Fuel 4). These equations are as follows:

A. Calculation of fuel density:

fuel density = specific gravity $\frac{60°F}{60°}$ X density of water at 60°F

B. Calculation of carbon weight fraction of the fuel (3):

$$\text{Carbon weight fraction} = A(W)\frac{Dg}{Df} + B(K)\frac{De}{Df}$$

where:

A = volume percent of gasoline used in fuel mixture
W = carbon weight fraction of gasoline used in fuel mixture
Dg = density of gasoline used in fuel mixture (g/gal)
Df = density of gasohol fuel (g/gal)
B = volume percent of ethanol used in fuel mixture
K = carbon weight fraction of ethanol used in fuel mixture = .5214
De = density of ethanol used in fuel mixture = 2979.18 (g/gal)

C. Calculation of carbon weight fraction of exhaust HC:

1) This calculation involves no equations only 2 assumptions.

a) For gasoline, the carbon weight fraction of the exhaust HC is the same as the carbon weight fraction of the fuel.

b) For gasohol, the fraction of ethanol contained in the exhaust is minimal (it is less than .1% of the measured exhaust hydrocarbons (3)). Thus, the carbon weight fraction of the exhaust HC for gasohol will be the same as the carbon weight fraction for the gasoline used in the fuel mixture.

Appendix E

Individual Test Results

Individual Test Data
1979 LEBARON

Fuel	Test	Date	FTP (gm/mi) HC	CO	NO_x	CO_2	mpg C.B.	Vol.	SHED (gm) DBL	HS	Total	Can. Wt. (gm) DBL	HS	Tot. Vap. (gm) DBL	HS	Total
Fuel 1	1	6/22/80	.72	13.7	1.76	534.	16.4	16.4	1.78	2.15	3.93	21.4	9.3	23.18	11.45	34.63
	2	6/25/80	.69	12.8	1.68	532.	16.5	16.5	1.19	2.36	3.55	24.3	9.3	25.49	11.66	37.15
	3	6/26/80	.72	14.2	1.87	533.	16.4	—	1.31	2.63	3.94	25.2	10.2	26.51	12.83	39.34
Fuel 2	1	7/6/80	.48	7.5	1.33	533.	16.7	16.5	1.51	3.30	4.81	18.9	9.6	20.41	12.90	33.31
	2	7/7/80	.58	6.9	1.87	534.	16.6	16.5	1.53	4.00	5.53	21.2	10.2	22.73	14.20	36.93
	3	7/9/80	.55	8.6	1.76	537.	16.5	16.4	1.45	3.71	5.16	22.3	9.2	23.75	12.91	36.66
Fuel 3	1	7/15/80	.52	8.0	1.85	524.	16.3	16.4	1.82	3.41	5.23	23.1	14.6	24.92	18.01	42.93
	2	7/17/80	.58	8.4	1.85	519.	16.5	16.6	1.72	3.50	5.22	26.2	13.9	27.92	17.40	45.32
	3	7/19/80	.55	8.0	1.82	525.	16.3	16.3	1.90	3.18	5.08	25.8	20.0	27.70	23.18	50.88
Fuel 4	1	7/20/80	.68	12.1	1.88	521.	16.5	—	2.17	3.61	5.78	30.9	12.6	33.07	16.21	49.28
	2	7/22/80	—	—	—	—	—	—	3.11	3.05	6.16	29.5	12.5	32.61	15.55	48.16
Fuel 1	1	7/23/80	.68	13.5	1.95	533.	16.4	—	1.22	2.57	3.79	26.0	10.1	27.22	12.67	39.89
	2	7/24/80	—	—	—	—	—	—	1.18	2.57	3.75	25.6	9.0	26.78	11.57	38.35

Key: C.B. = FTP Carbon Balance Fuel Economy
Vol. = Volumetric Fuel Economy
DBL = Diurnal Breathing Loss
HS = Hot Soak
Can. Wt. = Canister Weight Gain
Tot. Vap. = Total Vapor Generated

Individual Test Data

1979 REGAL

Fuel	Test	Date	FTP (gm/mi) HC	FTP (gm/mi) CO	FTP (gm/mi) NO_x	FTP (gm/mi) CO_2	mpg C.B.	mpg Vol.	SHED (gm) DBL	SHED (gm) HS	SHED (gm) Total	Can. Wt. (gm) DBL	Can. Wt. (gm) HS	Tot. Vap. (gm) DBL	Tot. Vap. (gm) HS	Tot. Vap. (gm) Total
FUEL 1	1	6/29/80	1.00	7.4	3.06	469.	18.9	19.2	3.83	2.92	6.75	21.1	7.1	24.93	10.02	34.95
	2	6/30/80	.91	6.7	2.83	471.	18.9	19.1	2.50	3.00	5.50	22.5	7.8	25.00	10.80	35.80
	3	7/2/80	.91	6.9	3.00	477.	18.6	18.9	2.68	3.03	5.71	22.1	6.8	24.78	9.83	34.61
FUEL 2	1	7/6/80	1.10	5.2	1.57	486.	18.3	18.7	2.86	4.85	7.71	17.5	8.8	20.36	13.65	34.01
	2	7/7/80	1.03	6.4	2.25	481.	18.4	—	3.32	4.66	7.98	19.0	8.4	22.32	13.06	35.38
	3	7/9/80	.97	6.3	2.57	482.	18.4	18.6	4.14	5.33	9.47	18.9	8.8	23.04	14.13	37.17
FUEL 3	1	7/15/80	.76	4.4	2.91	470.	18.3	18.5	6.55	4.24	10.79	21.4	9.7	27.95	13.94	41.89
	2	7/17/80	.79	4.5	2.93	479.	18.0	18.4	5.83	4.27	10.10	22.6	13.0	28.43	17.27	45.70
	3	7/18/80	.77	4.6	2.73	467	18.5	18.6	4.96	4.01	8.97	23.3	13.9	28.26	12.91	46.17
FUEL 4	1	7/21/80	1.08	7.9	3.06	474.	18.3	—	7.91	2.57	10.48	20.4	11.6	28.31	14.17	42.88
	2	7/22/80	—	—	—	—	—	—	6.03	2.63	8.66	23.3	11.8	29.33	14.43	43.76
FUEL 1	1	7/23/80	—	—	—	—	—	—	4.40	1.74	6.14	21.6	8.2	26.00	9.94	35.94
	2	7/24/80	1.25	8.3	3.14	460.	19.2	—	3.30	1.54	4.84	21.9	8.6	25.20	10.14	35.34

Key: C.B.= FTP Carbon Balance Fuel Economy
Vol.= Volumetric Fuel Economy
DBL = Diurnal Breathing Loss
HS = Hot Soak
Can. Wt. = Canister Weight Gain
Tot. Vap. = Total Vapor Generated