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Long-Term Methanol Vehicle Test Program

Final Subcontract Report
1 November 1992 – 1 February 1995

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Texas Tech University
Lubbock, Texas

National Renewable Energy Laboratory
1617 Cole Boulevard
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A national laboratory of the U.S. Department of Energy
Managed by the Midwest Research Institute
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1. Background and Objective

Methanol, one of the leading alternatives to gasoline as a motor vehicle fuel, has been highlighted in national competitions such as the Society of Automotive Engineers (SAE) Methanol Marathon in 1989 and the SAE Methanol Challenge in 1990, but little has been done in the area of long-term testing of methanol as a motor vehicle fuel. To address this shortcoming, a 1988 Chevrolet Corsica was modified by Texas Tech University to serve as a test bed to determine the long-term effects of methanol on engine and emission systems performance. The vehicle was previously modified to operate on M85 for the SAE Methanol Marathon/Challenge competitions; it was further modified for M100 operation for the long-term test program.

The objective of this project was to determine the effects of methanol fuel on engine performance and exhaust emissions during long-term use. Engine wear, gasket performance, fuel economy, emissions level, oil consumption, and overall vehicle performance were monitored over approximately 22,000 miles of vehicle operation. Vehicle performance, oil consumption, and emissions baselines were established initially to be used for comparative purposes during the program. The engine was removed from the vehicle and disassembled, and all bearing and ring clearances and cam profiles were measured to determine any preexisting wear. All gaskets, seals, bearings, and piston rings were replaced. The cylinder bore was honed, valve and valve seats were lapped, and the crankshaft journals were polished. Higher flow rate fuel injectors supplied by AC Rochester were installed and the computer system was calibrated for M100 fuel.

At the completion of the program, after the mileage accumulation phase, the vehicle emissions level, oil consumption, and engine performance were again determined. The engine was removed from the vehicle, disassembled, and engine component wear was determined and compared with the initial condition.

2. Vehicle Modifications

The Corsica was initially modified to operate on M85 for the SAE Methanol Marathon/Challenge competitions [1 and 2]. The vehicle won 2nd place overall in the 1990 Methanol Challenge, placing 1st in endurance fuel economy, 2nd in acceleration, and demonstrating excellent emissions and maneuverability. Table 1 summarizes the major event rankings for the Texas Tech Corsica.

Table 1. Major Event Rankings for TTU Corsica in 1990 SAE Methanol Challenge

<table>
<tr><td colspan="4">2nd Place Overall</td></tr>
<tr><td colspan="4">1st Place Endurance Fuel Economy</td></tr>
<tr><td colspan="4">2nd Place Acceleration</td></tr>
<tr><td colspan="4">FTP Emissions Results (g/mi)</td></tr>
<tr><td>HC</td><td>0.04</td><td>NO_x</td><td>0.71</td></tr>
<tr><td>NMHC</td><td>0.03</td><td>CH_3OH</td><td>0.29</td></tr>
<tr><td>CO</td><td>0.60</td><td>OMHCE</td><td>0.16</td></tr>
<tr><td colspan="4">FTP Fuel Economy Results
(miles per gallon gasoline equivalent)</td></tr>
<tr><td colspan="2">City</td><td colspan="2">21.6</td></tr>
<tr><td colspan="2">Highway</td><td colspan="2">41.0</td></tr>
<tr><td colspan="2">55/45 City/Highway</td><td colspan="2">27.4</td></tr>
</table>

A methanol-compatible fuel system (tank, pump, lines, fuel rail, and injectors) was installed for the SAE competitions. GM delivered the Corsica with a computer interface which allowed modifications to be made to the engine control maps during engine operation. The engine stroke was increased to take advantage of the increased amount of exhaust product and slower burning characteristics of methanol. To ensure good fuel economy, the bore was decreased to maintain a displacement of 2.8 liters. The crankshaft from a 1990 3.1-liter GM V-6 engine was used to achieve a stroke increase from 2.99 inches to 3.31 inches. Because methanol has a higher octane rating than gasoline, the compression ratio was increased to 11.7:1 by installing custom flat-top pistons with a centered pin-bore. The piston material contains a high silicon content for low coefficient of thermal expansion, good wear resistance, and high-temperature strength. The top piston ring was changed to a chrome ring to maximize the amount of heat retained in the combustion chamber to enhance the vaporization of fuel. The oil ring was also changed to reduce friction. A custom camshaft was employed to compensate for the slow burn characteristics of methanol. The lobe centers and duration were changed to allow a longer burn time during the power stroke. Cam specifications are presented in Table 2. Roller-tip rocker arms were used to reduce friction and valve guide wear. To compensate for the increase in exhaust flow, a larger 2-1/4-inch exhaust pipe diameter was used between the exhaust manifold and the catalytic converter. From the catalytic converter, the exhaust pipe diameter is 2-1/2 inches. Allied-Signal, Inc., Tulsa, Oklahoma, provided the specially designed light-off and main catalysts to control exhaust emissions. The light-off converter is located near the exhaust manifold in order to reach operating temperature as quickly as possible after engine start. Heated air from around the exhaust manifold is supplied to the air cleaner at temperatures below 30°C to enhance cold starting and driveability.

To increase fuel economy, the 5th gear ratio was lowered from 0.72:1 to 0.603:1. This resulted in a decrease in engine speed at 60 mph from 2200 to 1875 rpm. This modification takes advantage of the increased torque the engine produces. To prevent body roll in tight cornering, a larger sway bar and gas shocks were installed at the rear axle. These additions provided greater driving stability to the vehicle.

3. Engine Calibration and Fuel Properties

At program initiation after the engine was installed in the Corsica, chassis dynamometer testing was accomplished for engine/vehicle final calibration and performance evaluation. Rich conditions under deceleration were experienced and could not be corrected due to lack of electronic control module (ECM) deceleration table addresses. As a result, the vehicle experienced a slight idle instability after deceleration to a stop. The ECM calibration tables are included in Appendix A. Engine starting was acceptable at temperatures above 15°C, but considerable difficulty was experienced in starting the vehicle during winter conditions. As a result, the engine accumulated an abnormal amount of time under cold-cranking conditions with inadequate lubrication

A problem arose during the pretest engine dynamometer testing with the M100 fuel. This fuel had been stored for over a year, and upon opening a 55-gallon drum an atypical smell was noted as compared to that of M100 racing fuel. This fuel was used during the first series of dynamometer tests and the engine control system calibration

Table 2. Camshaft Specifications as Measured with the Cam Doctor

	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6	Avg	Variance	
Intake & Exhaust									
Lobe Center Sep	111.1	111.0	110.9	110.8	111.1	111.1	111.0	0.3	Cam Deg
Valve Overlap	-27.6	-27.5	-27.2	-27.2	-27.8	-28.0	-27.5	0.4	Crank Angle
Intake									
Valve Opening	-7.8	-7.8	-7.6	-7.6	-7.9	-8	-7.8	0.2	Deg BTDC
Lobe Center	104.6	104.5	104.4	104.3	104.5	104.5	104.5	0.1	Deg ATDC
Valve Closure	22.5	22.5	22.2	22.2	22.2	22.1	22.3	0.2	Deg ABDC
Duration	194.7	194.7	194.6	194.6	194.3	194.1	194.5	0.3	Crank Deg
Max Cam Lift	0.26031	0.26028	0.25992	0.25988	0.25854	0.2585	0.25957	0.00091	Inch
Net Valve Lift	0.39047	0.39041	0.38988	0.38982	0.38781	0.38776	0.38936	0.00136	Inch
Lobe Area	18.61	18.64	18.63	18.61	18.47	18.45	18.57	0.09	In * Deg
Exhaust									
Valve Opening	34.1	34.2	33.9	34	34.1	34	34.1	0.1	Deg BTDC
Lobe Center	117.5	117.5	117.4	117.3	117.6	117.5	117.5	0.1	Deg ATDC
Valve Closure	-19.8	-19.8	-19.6	-19.6	-19.9	-20	-19.8	0.2	Deg ABDC
Duration	194.3	194.4	194.3	194.4	194.2	194	194.3	0.2	Crank Deg
Max Cam Lift	0.25933	0.25917	0.25921	0.25906	0.25902	0.25906	0.25914	0.00016	Inch
Net Valve Lift	0.389	0.38876	0.38882	0.38858	0.38852	0.38858	0.38871	0.00024	Inch
Lobe Area	18.47	18.54	18.5	18.53	18.46	18.44	18.49	0.05	In * Deg

was difficult due to extremely rich conditions and exhaust temperatures were lower than typical. After a few minutes of operation the O_2 sensor failed. The fuel was then tested using a procedure developed by V-P Hydrocarbons, which involves the addition of 10 parts hydrochloric acid and calcium chloride solution, 5 parts phenolphtalein and methanol solution, and 10 parts sodium hydroxide solution to 30 parts of the tested methanol. The result was a very cloudy solution, which, according to the test protocol, was unacceptable. Laboratory-grade methanol (99.98%) was also tested and resulted in a clear solution. The fuel was also used in the vehicle after the engine was reinstalled. When driving, a wide variance in the block learn memory was noted; thus, the engine idle was erratic and unstable. Occasionally, the engine would die during rapid acceleration.

Air Products and Chemicals, Allentown, Pennsylvania, which was providing the M100 for the program at no cost, was contacted and two samples of the fuel were sent to them for analysis. Gas chromatographic analysis of the samples did not disclose any obvious reasons why this fuel did not perform satisfactorily in the Corsica. This fuel was discarded and fresh fuel from the Air Products facility in LaPorte, Texas, was used during the remainder of the program without any further problems. Table 3 shows assays of the typical product and the two samples analyzed by Air Products.

Table 3. Methanol Composition

Constituent	M100 Assay (Wt.%)	Sample 1 (Wt. %)	Sample 2 (Wt. %)
1. Methanol	96.590	97.030	97.060
2. Dissolved Gases (Air+CO_2)	0.126	0.000	0.000
3. Dimethyl Ether	0.012	0.000	0.000
4. Methyl Formate	0.924	0.700	0.700
5. Water	0.605	0.550	0.550
6. Ethanol	0.678	0.630	0.640
7. Methyl Acetate	0.166	0.140	0.130
8. n–Propanol	0.260	0.320	0.320
9. Methyl Ethyl Ketone	0.048	0.010	0.010
10. SEC–Butanol	0.029	0.040	0.030
11. ISO–Butanol	0.036	0.030	0.030
12. N–Butanol	0.137	0.120	0.120
13. ISO–Pentanol	0.038	0.070	0.060
14. 1–Pentanol	0.080	0.060	0.060
15. N–Hexanol	0.034	0.030	0.020
16. Aliphatic Oil	0.235	0.010	0.040
17. Isopropanol	0.000	0.010	0.010
18. t–Butanol	0.000	0.006	0.008
19. Unknowns	0.000	0.240	0.210—

4. Mileage Accumulation

The mileage accumulation phase of the project occurred between the initial and final Federal Test Procedure (FTP) testing at Southwest Research Institute (SwRI) (from January 1993 to December 1994). The vehicle was driven under city and highway conditions and relatively few problems were experienced. The hydraulic clutch slave cylinder failed during a full-throttle acceleration drive and the mass air-flow sensor was replaced after the mounting boss broke. The vehicle pulled a two-wheel trailer loaded with two 55-gallon drums of methanol from Lubbock to San Antonio, Texas and Lubbock to Austin, Texas with exceptional performance. Figure 1 shows the Corsica during a road trip to San Antonio. Note the fuel trailer necessary for long trips. The vehicle was exhibited during the 4th Annual Texas Alternative Fuels Market Fair and Symposium in Austin on June 6-8, 1993, and participated in the 1993 Fourth of July parade in Lubbock, Texas. Figure 2 shows the vehicle on display at the Market Fair in Austin, Texas.

The only serious problem encountered during the mileage accumulation phase of the program was related to fuel pump failures. In March 1994 the original fuel pump in the vehicle failed. This pump had been in the vehicle since the inception of the long-term methanol program but was the third pump installed in the vehicle during the two years of competition (1989-1990). At the time of failure this pump had been in service for approximately two years. Contact with AC Rochester at the time of failure indicated that this particular pump was subject to electrical contact corrosion in which copper from the electrical contact was taken into solution with the methanol. When

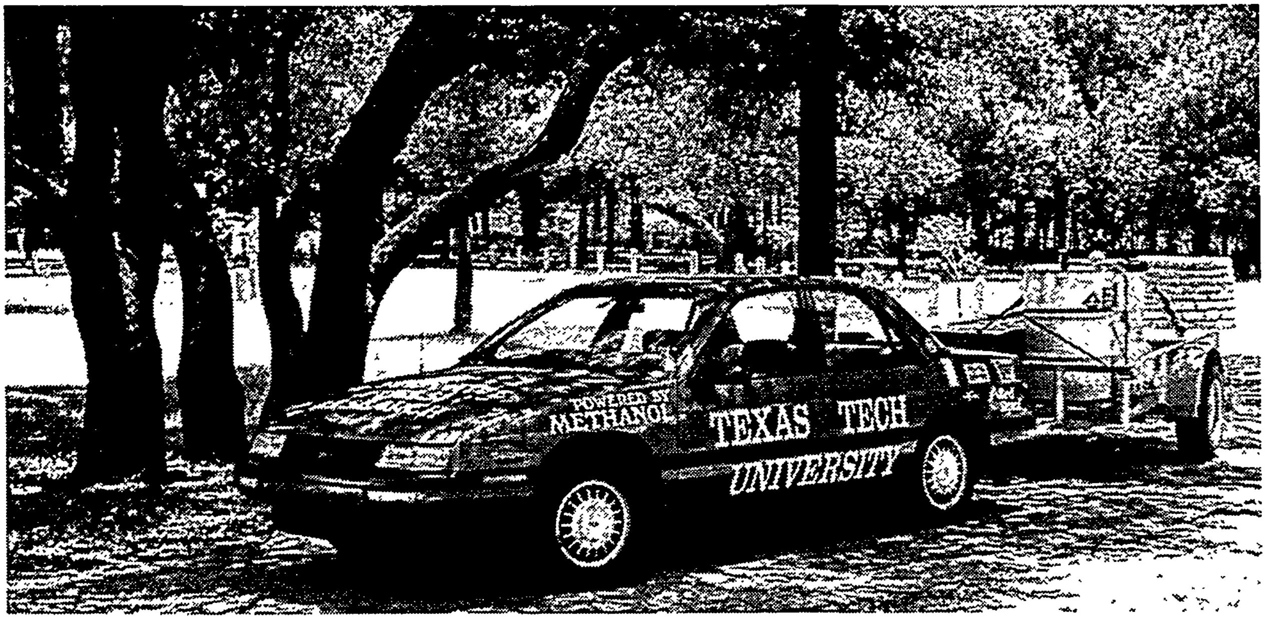

Figure 1. Test vehicle during road trip to San Antonio

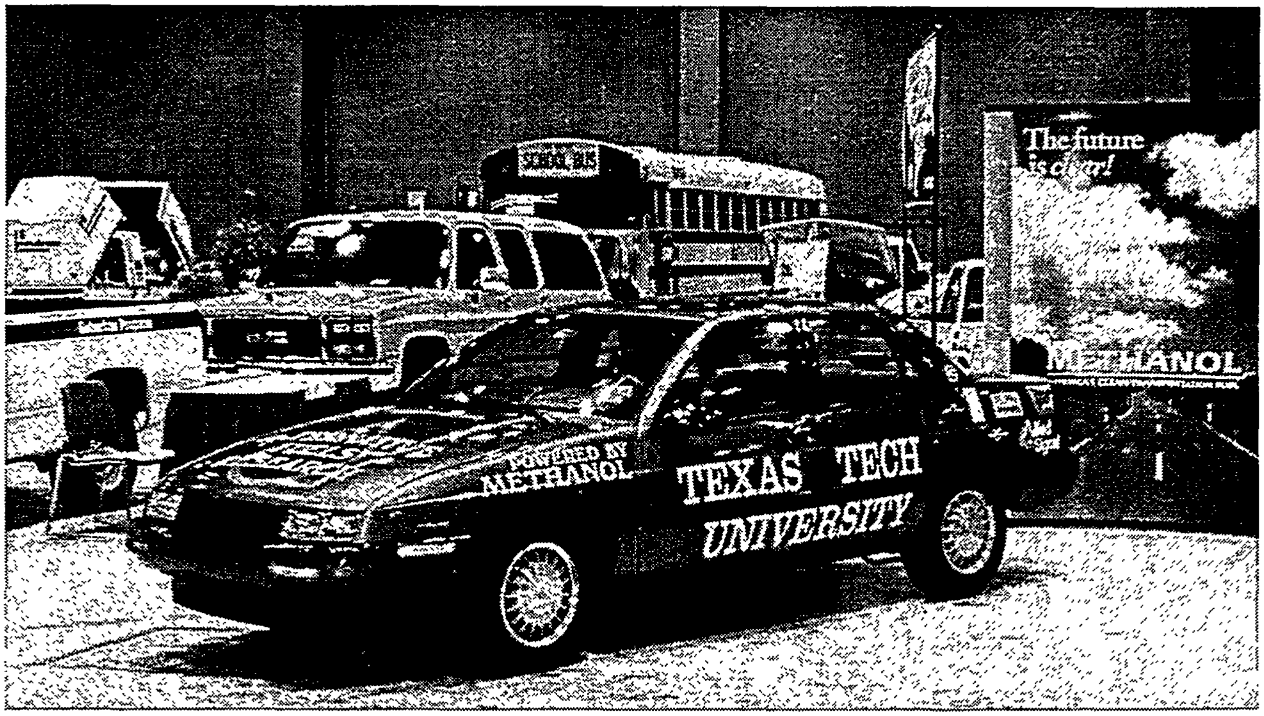

Figure 2. Test vehicle on display at the 4th Annual Texas Alternative Fuels Market Fair and Symposium in Austin

the amount of copper reached a certain level it appeared to precipitate out of solution and clog the pump, rendering it inoperative.

The failed pump was replaced with a new pump obtained from AC Rochester. The replacement pump lasted only a few minutes before it also failed. AC Rochester personnel indicated that some pumps were manufactured with inadequate plating and that the type of failure experienced with this second pump was characteristic of this manufacturing problem. A third pump obtained from AC Rochester was then installed in the vehicle in late June 1994. This pump also failed shortly thereafter (approximately two weeks). This pump was returned to AC Rochester and from there was passed on to the General Motors Corporation (GM) Fuels and Lubricants Department for analysis. A fuel sample was also sent to GM since it was suggested that the M100 might be contributing to the failures. Personnel from Air Products and Chemicals were also brought into the failure analysis discussions at this time since they provided the M100 for the program. No report as to the results of this analysis was provided by GM.

A methanol-compatible fuel pump was then purchased from the local GM performance parts supplier. This pump was preconditioned by pumping gasoline through it for several hours before installing it in the vehicle. This pump performed satisfactorily for the remainder of the program (approximately six months).

5. Engine and Component Wear

Tear-down of the engine after the mileage accumulation showed indications of detonation in three cylinders and significant wear and scuffing on one cylinder wall. Cylinders 1, 2, and 6 showed normal wear of approximately 0.0005 in cylinder diameter. Figure 3 shows the piston from Cylinder 2 after removal from the engine. The pistons from Cylinders1 and 6 are similar. There is no indication of wear on the piston itself and the rings still show the initial marks and imperfections. Note also the dark portion of the top of the second ring, which indicates that only a portion of the ring surface was in contact with the cylinder wall. Finally, there is no indication of combustion products or carbon buildup between the first and second rings of pistons from Cylinders 1, 2, and 6.

Cylinders 3 and 5 showed evidence of some detonation. The undersides of both pistons were lightly discolored, indicating excess heating typical of the higher temperatures produced by detonation. The rod bearings from these cylinders also showed some deformation typical of detonation. The piston from Cylinder 3 is shown in Figure 4. Note the dark deposits between the first and second rings. These deposits often result from detonation-produced flutter of the top piston ring. Also note that the top ring is very polished which indicates more than normal wear.

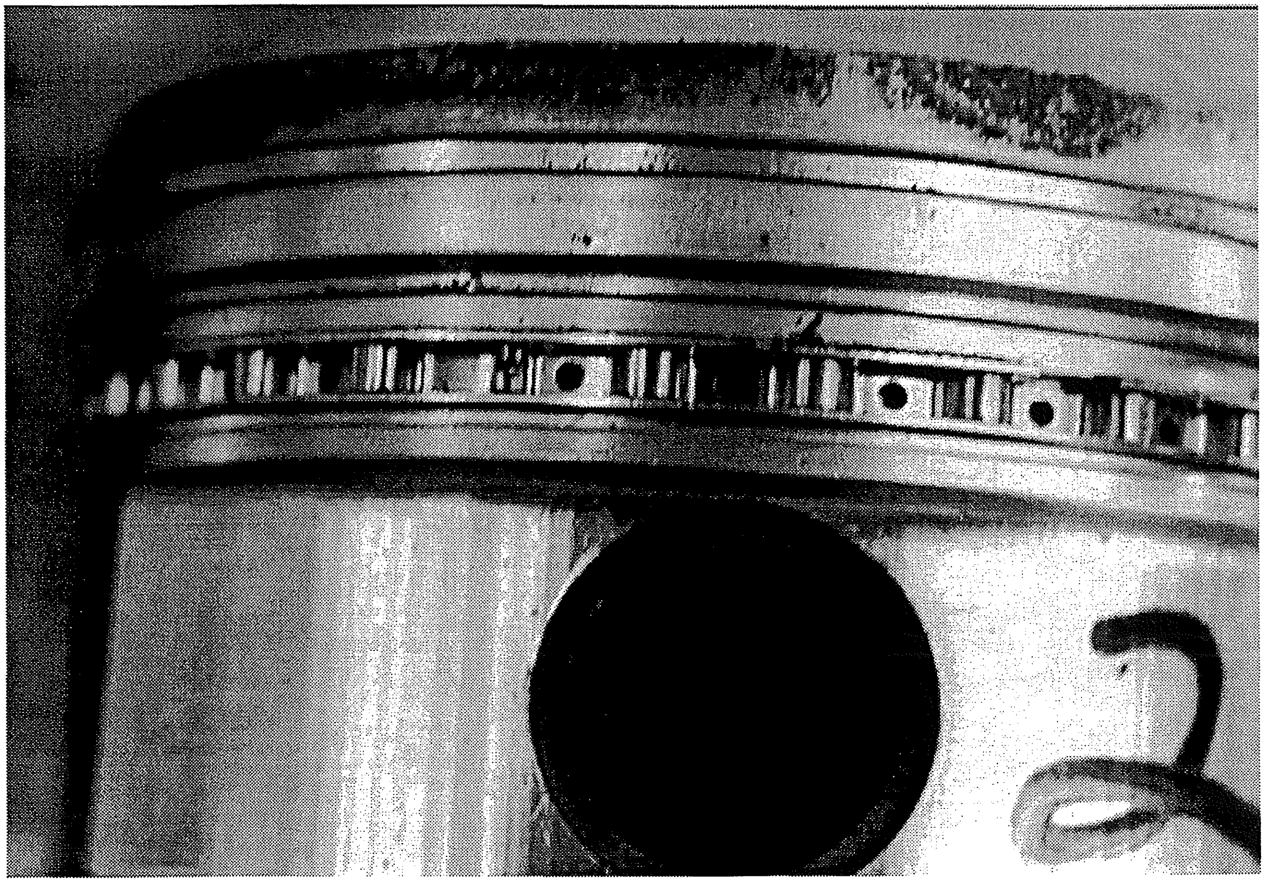

Figure 3. Side view of piston from Cylinder 2

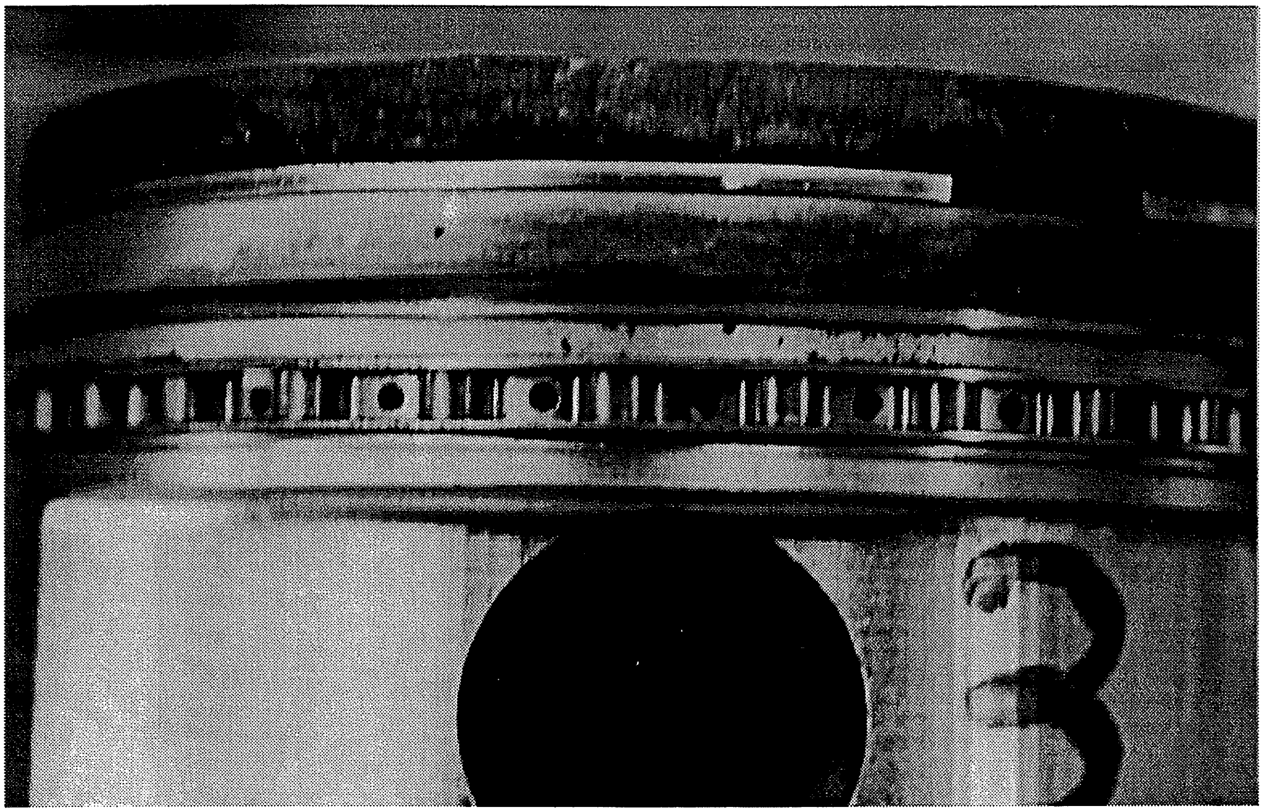

Figure 4. Side view of piston from Cylinder 3

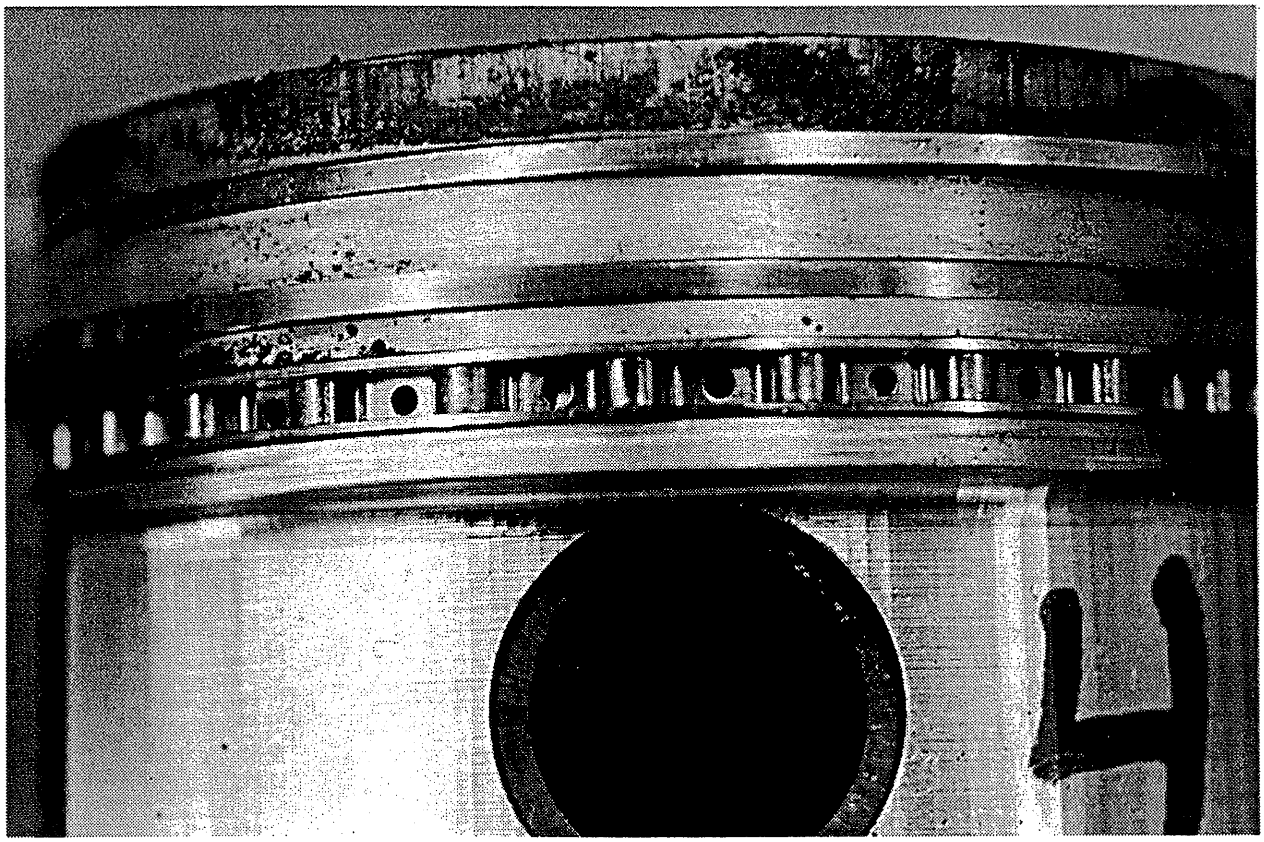

Figure 5. Side view of piston from Cylinder 4

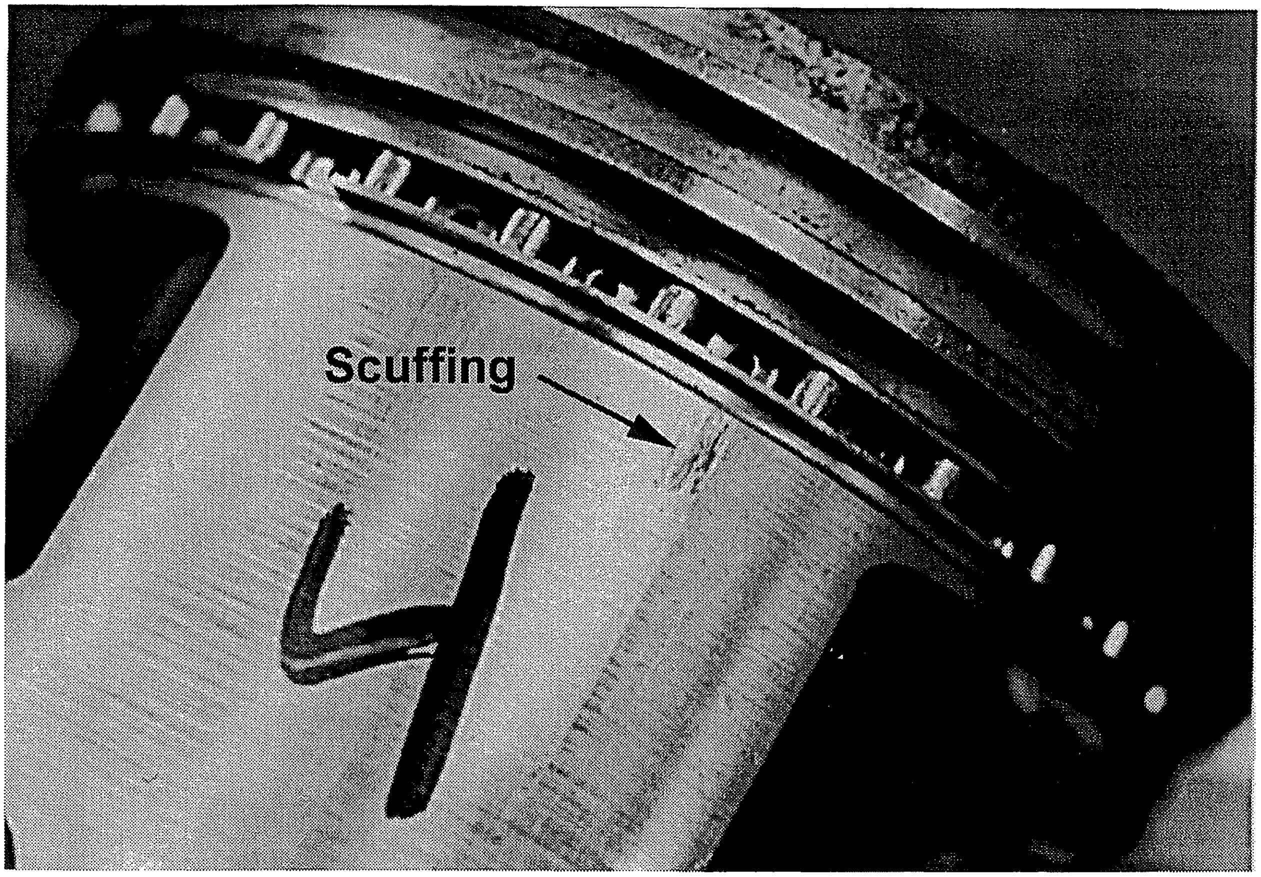

Figure 6. View of piston from Cylinder 4

Cylinder 4 showed the most significant abnormal wear. Views of the piston from Cylinder 4 are shown in Figures 5 and 6. Both the top and second ring show polished surfaces, indicating excessive wear for 22,000 miles of operation. There are almost no signs of the original markings on the rings. Some indication of scuffing of the piston surface between the rings is also apparent. Scuffing of the piston below the oil ring is clearly evident in Figure 6. The wall of Cylinder 4, depicted in Figure 7, clearly shows excessive scuffing. Note that the scuffing extends all the way to the top of the cylinder, above the highest position of the top ring. The scuffs in the cylinder become more pronounced at a point on the cylinder wall which coincides with the piston location a few crankshaft degrees past TDC, approximately where the force on the piston due to the combustion gases rapidly increases. The bottom of Piston 4 showed excessive heating and the rod bearings from Cylinder 4 were deformed in a manner typical of detonation. Cylinder 4 experienced the most severe detonation. Figure 8 shows the combustion chamber for Cylinder 4. Note the absence of the ceramic insulator in the spark plug. The insulator was probably dislodged by detonation. Otherwise the combustion chamber was clean and relatively free of deposits.

The wear experienced in Cylinder 4 and, to a lesser extent, in Cylinders 3 and 5 (see Tables 4 and 5), is thought to be related to the washing down of the cylinder walls by fuel during coldstarting. The engine was very difficult to start during the winter

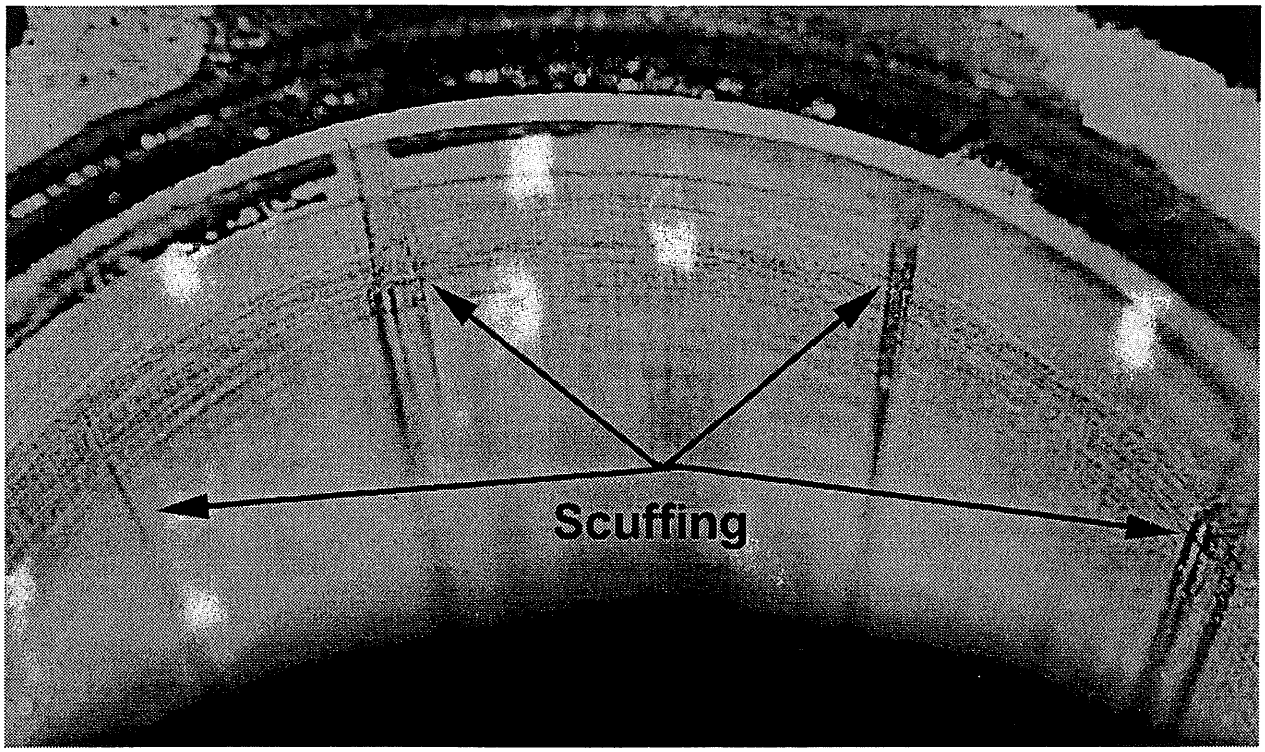

Figure 7. View of cylinder wall in Cylinder 4

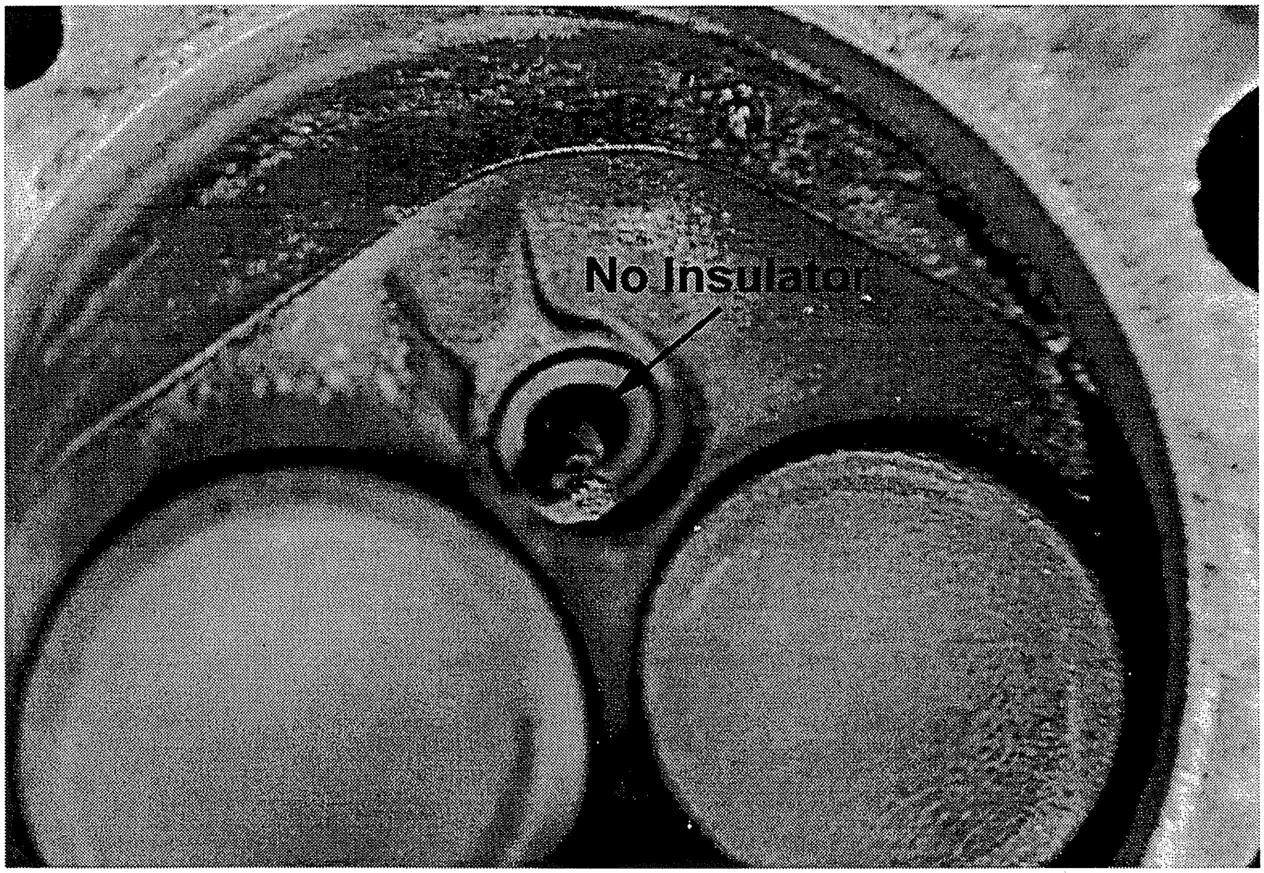

Figure 8. Cylinder head showing Cylinder 4 combustion chamber

Table 4. Short-Block Measurements Before Mileage Accumulation

Cylinder block						
Cylinder bore diameter	**Cyl 1**	**Cyl 2**	**Cyl 3**	**Cyl 4**	**Cyl 5**	**Cyl 6**
Top	3.3303	3.3309	3.3303	3.3305	3.3305	3.3305
Bottom	3.3306	3.3309	3.3306	3.3312	3.3306	3.3309
Main bore (all ± 0.0005 in)	2.847 in		Deck Milled 0.04 in			
Deck height (all ± 0.001 in)	7.391 in					

Connecting rods		
Bore (all ± 0.0005 in)	2.125 in	Mass 440 g
Length (all 0.0005 in)	5.7 in	

Pistons	
Diameter (all ± 0.001 in)	Ring land clearance (all ± 0.0005 in)
Top 3.3225 in	Top 0.0022 in
Middle 3.3241 in	Middle 0.0015 in
Bottom 3.3264 in	Piston Height 1.416 in
Mass 329 g	

Piston pins		
Pin to piston bore clearance (all ± 0.0003 in)	0.0008 in	Mass 122 g

Piston rings	
Gap (all ± 0.0005 in)	
Top 0.0135 in	Mass 39 g
Middle 0.0085 in	Oil ring tension (pull) 11.5—12.0 lbf

Crankshaft		
Rod journal (all ± 0.0005 in)	1.9983	in
Main journal (all ± 0.0005 in)	2.6468	in
Stroke (all ± 0.0003 in)	3.31	in

Rod bearings	
Thickness (all ± 0.0005 in)	Average clearance 0.002 in
Max 0.0622 in	Mass 33 g
Min 0.0595 in	

Main bearings	
Thickness (all ± 0.0005 in)	Average clearance 0.002 in
Max 0.0958 in	Min 0.0929 in

months when temperatures were below 7 to 10°C. Hence, starting involved cranking the engine for several minutes. During the long cranking times methanol was continuously injected into the cylinder and washed the lubricating oil from the cylinder walls. The oil sample analysis for the oil change after the winter months of mileage accumulation showed high engine wear.

Table 5. Short-Block Measurements After Mileage Accumulation

Cylinder block						
Cylinder bore diameter	**Cyl 1**	**Cyl 2**	**Cyl 3**	**Cyl 4**	**Cyl 5**	**Cyl 6**
Top	3.3315	3.3311	3.3313	3.3316	3.3315	3.3315
Bottom	3.3308	3.331	3.3313	3.3312	3.331	3.3312
Main bore (all ± 0.0005 in)	2.847 in	Deck Milled	0.04 in			
Deck height (all ± 0.001 in)	7.391 in					
Connecting rods						
Bore (all ± 0.0005 in)	2.125 in	Mass	440 g			
Length (all ± 0.0005 in)	5.7 in					
Pistons						
Diameter (all ± 0.001 in)		Ring land clearance (all ± 0.0005 in)				
Top	3.3225 in	Top	0.0022 in			
Middle	3.3241 in	Middle	0.0015 in			
Bottom	3.3264 in	Piston Height	1.416 in			
Mass	329 g					
Piston pins						
Pin to piston bore clearance (all ± 0.0003 in)	0.0008 in	Mass	122 g			
Piston rings						
Gap (all ± 0.0005 in)						
Top	0.0155 in	Mass	39 g			
Middle	0.0105 in	Oil ring tension (pull)	11.5—12.0 lbf			
Crankshaft						
Rod journal (all ± 0.0005 in)	1.9983 in					
Main journal (all ± 0.0005 in)	2.6468 in					
Stroke (all ± 0.0003 in)	3.31 in					
Rod bearings						
Thickness (all ± 0.0005 in)		Average clearance	0.002 in			
Max	0.0623 in	Mass	33 g			
Min	0.0598 in					
Main bearings						
Thickness (all ± 0.0005 in)		Average clearance	0.002 in			
Max	0.0958 in	Min	0.0929 in			

In addition to the cylinder wall, piston, and ring wear described above, the exhaust valve guides showed approximately 0.001 in wear, which is not considered excessive. The bearings showed normal wear other than the detonation-associated wear on the rod bearings in Cylinders 3, 4, and 5. Tables 4 and 5 present the detailed short-block measurements for before and after mileage accumulation, respectively. Similarly, Tables 6 and 7 present the cylinder head measurements. Oil sample analyses also

Table 6. Cylinder Head Measurements Before Mileage Accumulation

	Cyl 1				Cyl 3				Cyl 5			
	Exhaust		Intake		Exhaust		Intake		Exhaust		Intake	
Valve stem dia (in)	0.3131		0.3138		0.3139		0.3136		0.3138		0.3132	
Valve dia (in)	0.315		0.3151		0.3151		0.3151		0.3149		0.3152	
Installed height (in)	1.72		1.72		1.71		1.72		1.71		1.715	
Shim thickness (in)	0.075		0.075		0.06		0.075		0.06		0.075	
Spring coil bind (in)	1.19		1.19		1.19		1.19		1.19		1.19	
Spring pressure (lbf)	95		95		95		95		95		95	
Retainer to seal (in)	0.54		0.54		0.54		0.54		0.54		0.54	
Seal thickness (in)	0.16		0.16		0.16		0.16		0.16		0.16	
Comb chamber (cc)	26.6		26.6		26.6		26.6		26.6		26.6	
	Cyl 2				Cyl 4				Cyl 6			
	Exhaust		Intake		Exhaust		Intake		Exhaust		Intake	
Valve stem dia (in)	0.3135		0.3137		0.3138		0.3138		0.3138		0.3138	
Valve dia (in)	0.3152		0.3152		0.3151		0.315		0.315		0.315	
Installed height (in)	1.73		1.725		1.72		1.715		1.715		1.715	
Shim thickness (in)	0.075		0.075		0.075		0.075		0.06		0.075	
Spring coil bind (in)	1.19		1.19		1.19		1.19		1.19		1.19	
Spring pressure (lbf)	95		95		95		95		95		95	
Retainer to seal (in)	0.54		0.54		0.54		0.54		0.54		0.54	
Seal thickness (in)	0.16		0.16		0.16		0.16		0.16		0.16	
Comb chamber (cc)	26.6		26.6		27.2		26.6		26.8		26.6	
Gasket surface milled (in)	0.04				Head gasket thickness (in)				0.068			
Total swept volume (cc)	472.38				Head gasket volume (cc)				11.56			
Compression ratio	11.72											

indicated high upper-cylinder wear. Oil sample analysis sheets are included in Appendix B.

Several oil leaks were noted around gaskets and seals. Figure 9 shows one such oil leak on the rear of the cylinder block. Perhaps the blowby of methanol into the crankcase during cold starting affected the gaskets and seals. All gaskets and seals have been sent to FEL-PRO for further analysis.

The detonation is thought to have been caused by injector wear. If the injectors experienced wear due to the low lubricity of methanol, they could have provided poor atomization of the fuel and/or too little fuel to some cylinders. Either condition could have provided an effectively lean mixture for some cylinders and thus promoted detonation in those cylinders. A visual inspection of the fuel injectors indicated that the injector for Cylinder 4 contained some foreign material in its exit. The injectors have been sent to SwRI for further testing and evaluation.

Table 7. Cylinder Head Measurements After Mileage Accumulation

	Cyl 1				Cyl 3				Cyl 5			
	Exhaust		Intake		Exhaust		Intake		Exhaust		Intake	
Valve stem dia (in)	0.3131	0.3129	0.3138	0.3135	0.3139	0.3135	0.3136	0.3134	0.3138	0.3137	0.3132	0.3129
Valve dia (in)	0.3152	0.3155	0.3152	0.3155	0.3151	0.3155	0.3152	0.3168	0.315	0.3155	0.3152	0.3158
Installed height (in)	1.72		1.72		1.71		1.72		1.71		1.715	
Shim thickness (in)	0.075		0.075		0.06		0.075		0.06		0.075	
Spring coil bind (in)	1.19		1.19		1.19		1.19		1.19		1.19	
Spring pressure (lbf)	95		95		95		95		95		95	
Retainer to seal (in)	0.54		0.54		0.54		0.54		0.54		0.54	
Seal thickness (in)	0.16		0.16		0.16		0.16		0.16		0.16	
Comb chamber (cc)	26.6		26.6		26.6		26.6		26.6		26.6	
	Cyl 2				Cyl 4				Cyl 6			
	Exhaust		Intake		Exhaust		Intake		Exhaust		Intake	
Valve stem dia (in)	0.3135	0.3134	0.3138	0.3136	0.3137	0.3135	0.3138	0.3132	0.3138	0.03136	0.3137	0.3134
Valve dia (in)	0.3153	0.3168	0.3152	0.3156	0.315	0.3155	0.3151	0.316	0.315	0.3155	0.3151	0.3155
Installed height (in)	1.73		1.725		1.72		1.715		1.715		1.715	
Shim thickness (in)	0.075		0.075		0.075		0.075		0.06		0.075	
Spring coil bind (in)	1.19		1.19		1.19		1.19		1.19		1.19	
Spring pressure (lbf)	95		95		95		95		95		95	
Retainer to seal (in)	0.54		0.54		0.54		0.54		0.54		0.54	
Seal thickness (in)	0.16		0.16		0.16		0.16		0.16		0.16	
Comb chamber (cc)	26.6		26.6		27.2		26.6		26.8		26.6	
Gasket surface milled (in)	0.04				Head gasket thickness (in)				0.068			
Total swept volume (cc)	472.38				Head gasket volume (cc)				11.56			
Compression.ratio	11.72											

6. Engine Performance

Engine performance at peak load was determined on a SuperFlow dynamometer before the engine was installed in the vehicle and again at the end of the mileage accumulation and after the final emissions and oil consumption tests were completed. Figures 10, 11 and 12 show the engine as mounted on the SuperFlow dynamometer. Corrected torque and power curves for the before and after tests are presented in Figures 13 and 14. Data from two runs during each test session on the dynamometer are shown. The low torque reading for one of the initial runs at 3750 rpm is due to fuel calibration. The calibration was adjusted and the curve smoothed, as the other initial data point for 3750 rpm indicates.

During the initial dynamometer tests the engine produced a maximum torque of 201 lbf-ft at 3750 rpm and a maximum power of approximately 161.5 hp at 5000 rpm. The end of project tests show maximum torque and power outputs of 192.4 lbf-ft at 4000 rpm and 155.4 hp at 5000 rpm. GM advertised the torque and power output of the stock 2.8-L engine on gasoline (with accessories) as 160 lbf-ft at 3600 rpm and 125 hp at 4500 rpm. These points are shown on the curves for reference. The engine showed

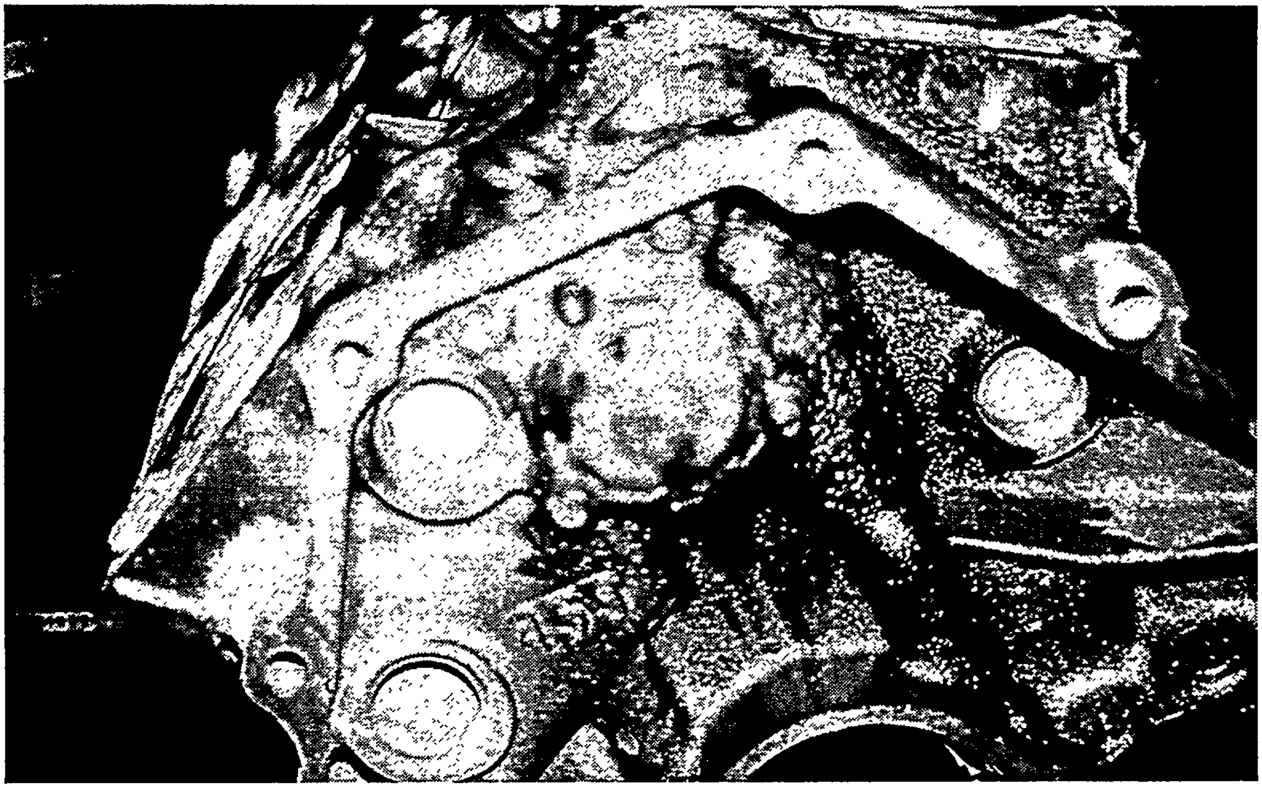

Figure 9. Rear of cylinder block showing oil leak

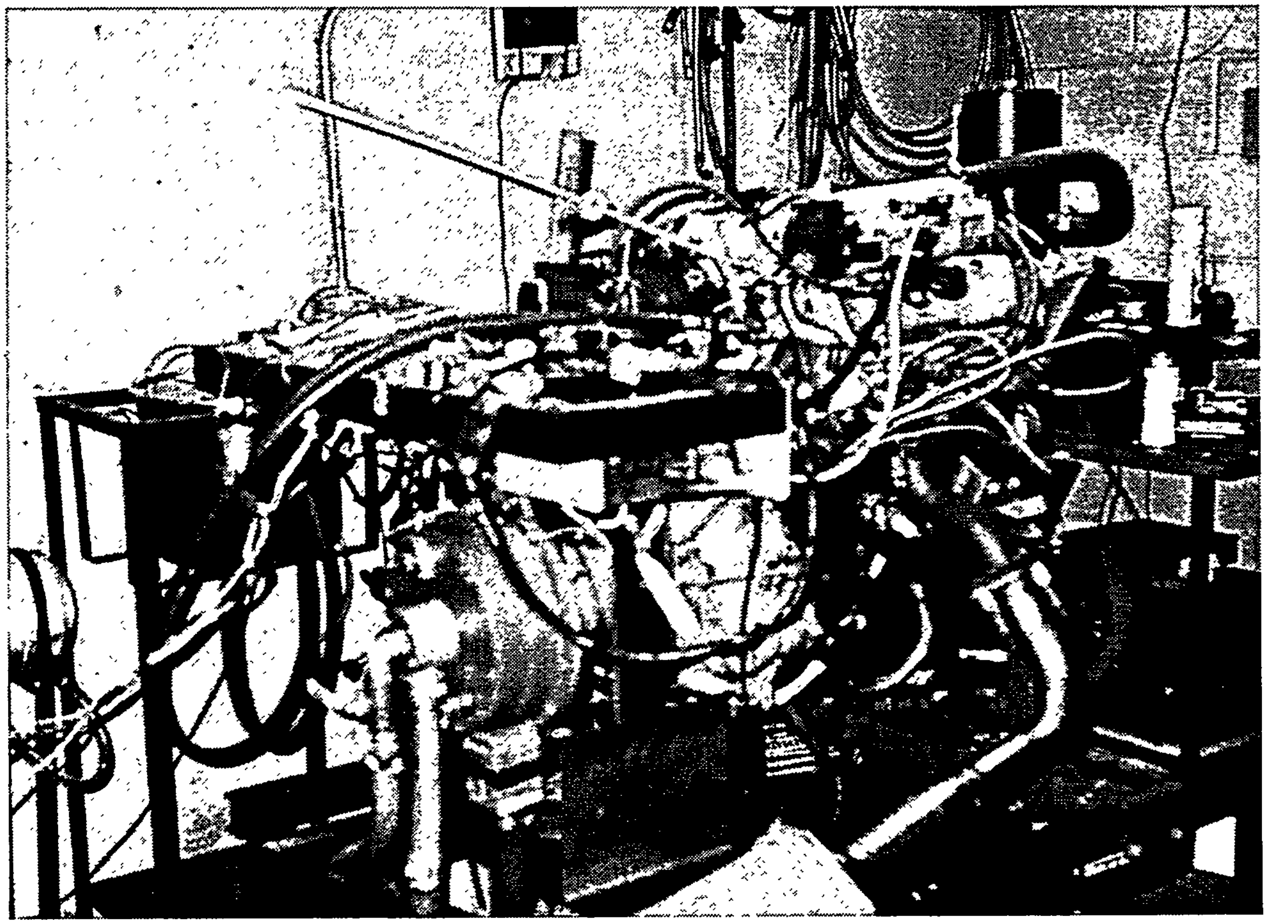

Figure 10. Engine mounted on SuperFlow dynamometer

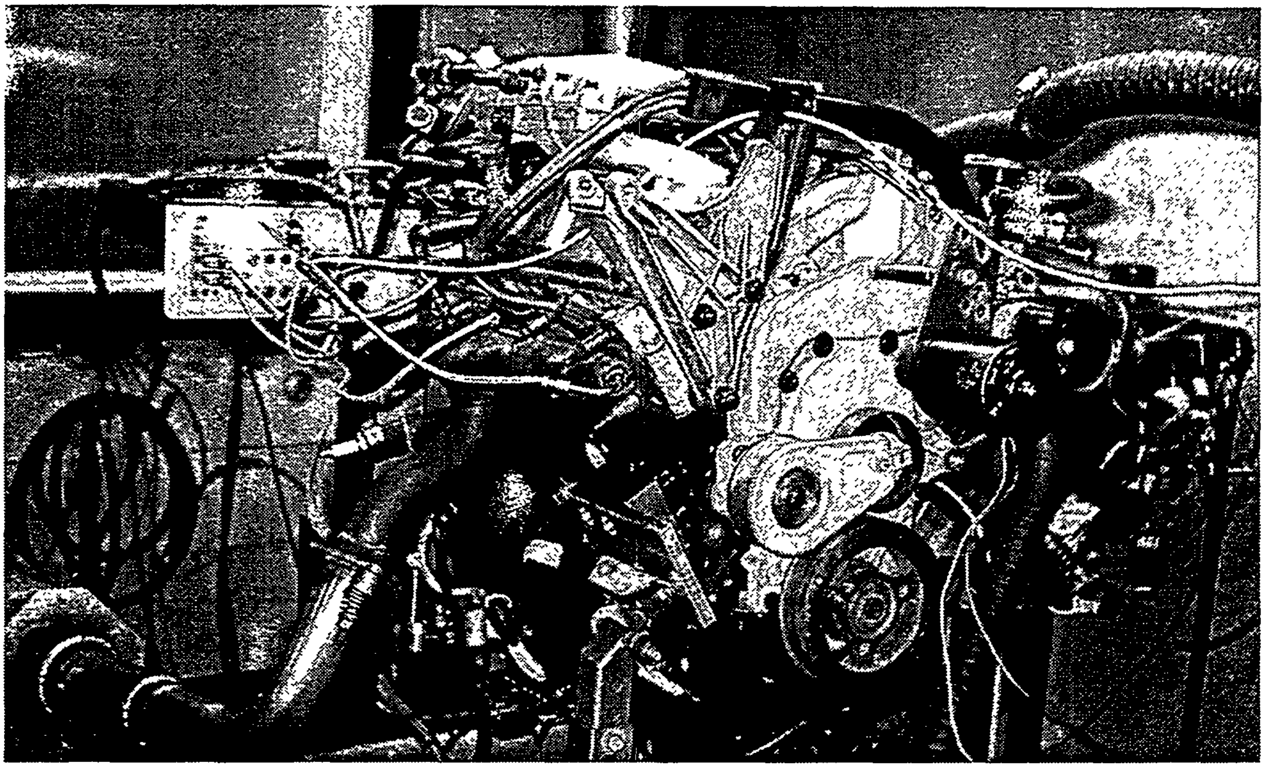

Figure 11. Engine mounted on SuperFlow dynamometer

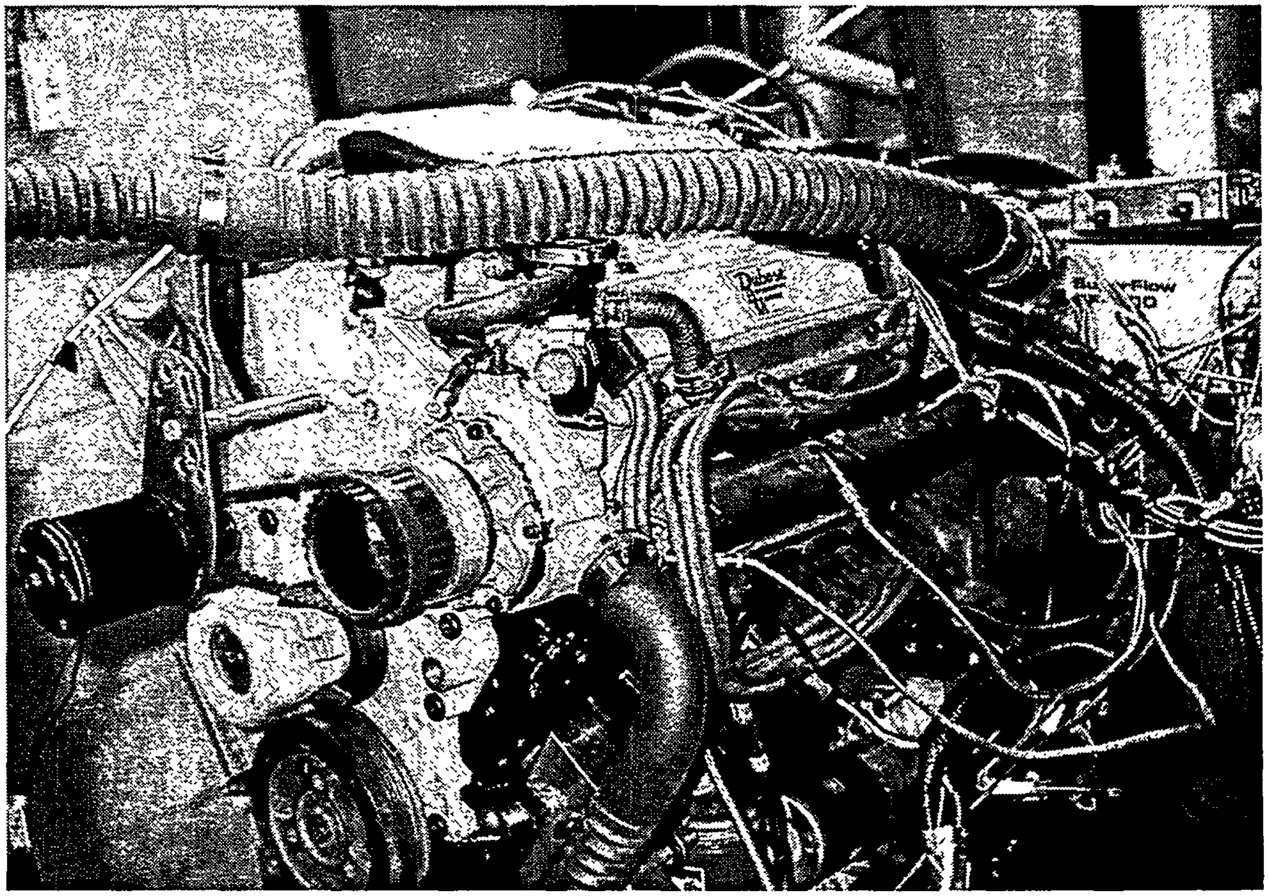

Figure 12. Engine mounted on SuperFlow dynamometer

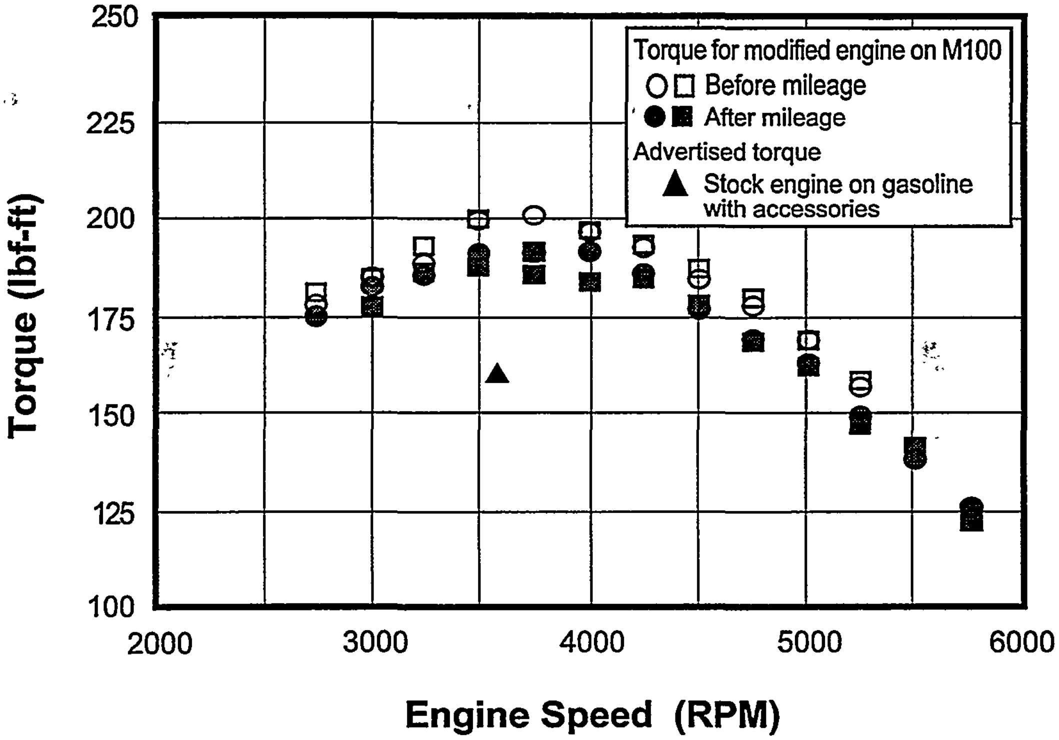

Figure 13. Engine torque output

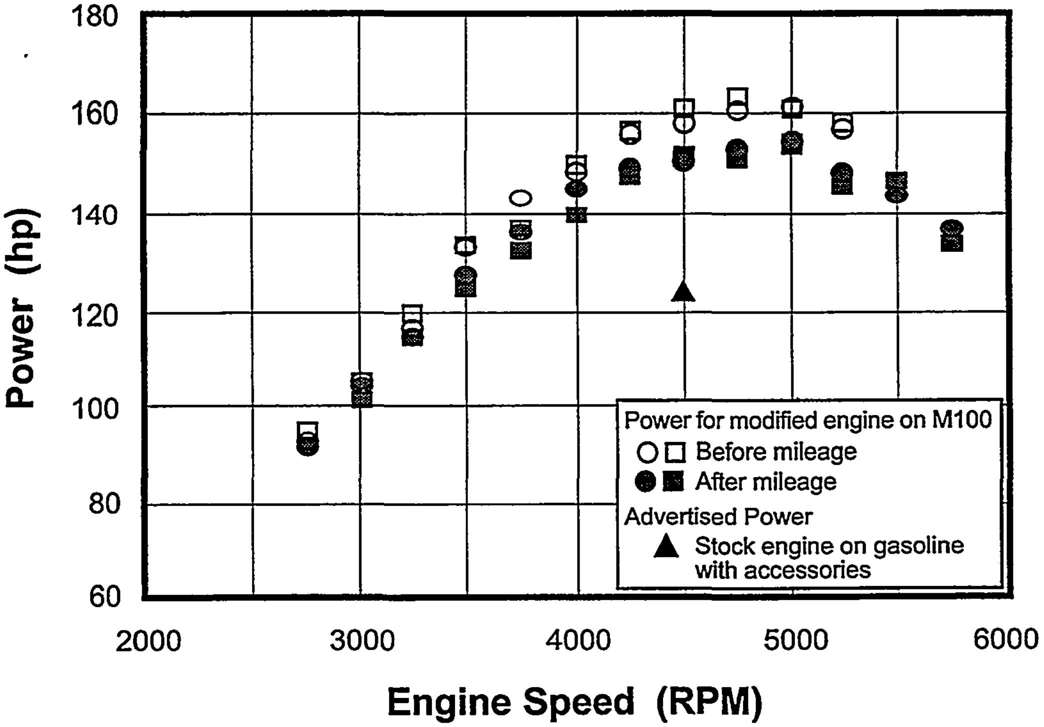

Figure 14. Engine power output

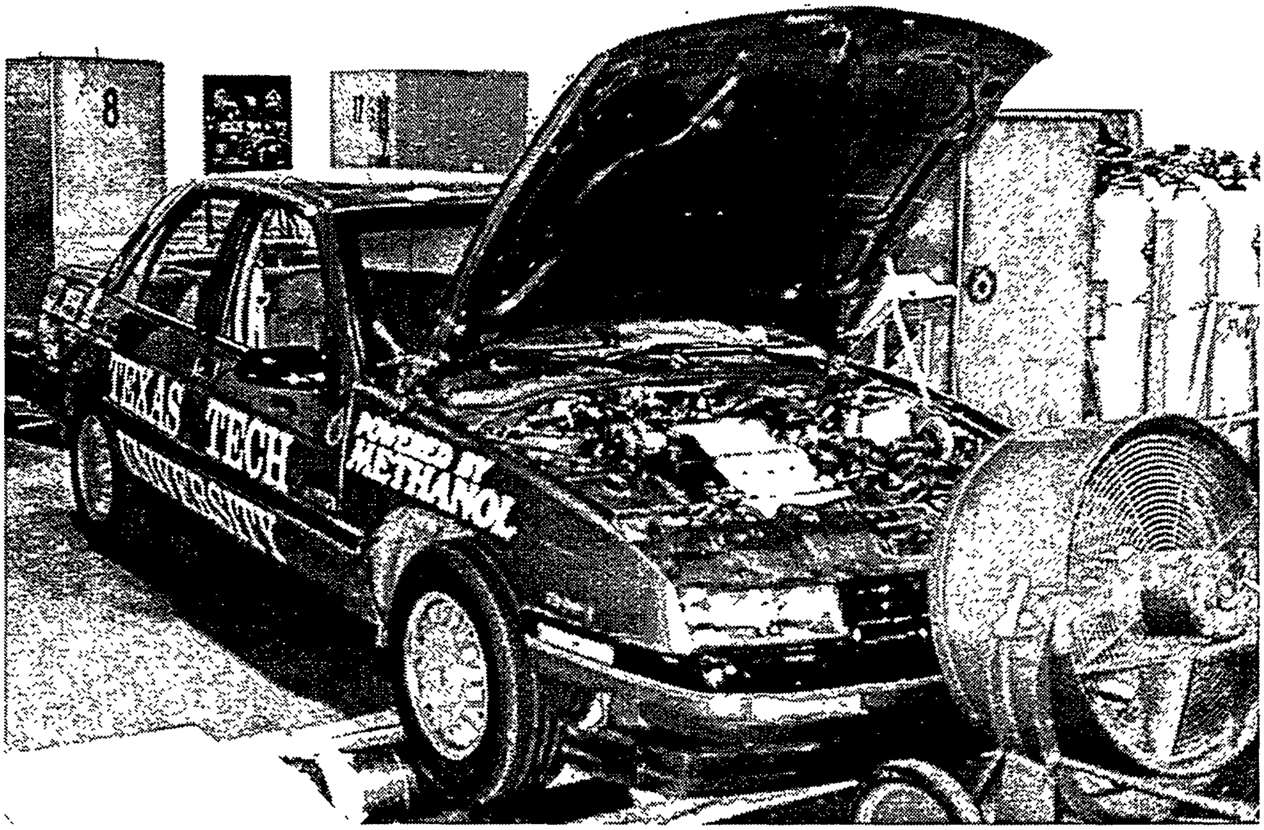

Figure 15. Vehicle during emissions tests at Southwest Research Institute

a decrease in maximum torque of about 4.3% and a decrease in maximum power of about 3.8% between the initial tests and the final tests. This amount of decrease is not considered unusual for 22,000 miles of operation; however, as was noted above, the engine suffered significant degradation in one cylinder.

7. Emissions And Fuel Economy

The vehicle was driven to SwRI in San Antonio, Texas, for full Environmental Protection Agency (EPA) FTP emissions testing at the beginning and completion of the program. Figure 15 depicts the vehicle during testing at SwRI. The emission test results at program initiation were very encouraging, with the vehicle meeting ultra-low emissions vehicle (ULEV) standards for all components except non-methane organic gases (NMOG). The pre- and post-test NMOG values are uncorrected since a reactivity adjustment factor (RAF) for M100 could not be obtained. Test results at program completion showed increased emissions for all exhaust components for all bags during the FTP testing, except non-methane hydrocarbons (NMHC). Emission results are given in Table 8. The SwRI reports are included in Appendix C.

The poorer emissions results during the second test are thought to have resulted from unburned fuel/air mixture that escaped the combustion process as a result of the scored

Table 8. Vehicle Emissions Results

Constituent	SwRI Test Jan. 1993 (gm/mi)	SwRI Test Dec. 1994 (gm/mi)	ULEV (gm/mi)
1. THC	0.48	1.167	—
2. CO	0.960	4.280	1.700
3. NO_x	0.150	0.690	0.200
4. CH_4	0.035	0.193	—
5. NMHC	0.011	0.004	—
6. Carbonyl	0.005	0.022	—
7. Alcohol	0.464	0.948	—
8. NMOG	0.479*	0.975*	0.040
9. Formaldehyde	0.0030	0.0200	0.008
10. Acetaldhyde	0.0002	0.0007	—
11. Acrolein	0.0000	0.0000	—
12. Acetone	0.0012	0.0007	—
13. Propionald	0.0000	0.0002	—
14. Crotonald	0.0000	0.0000	—
15. Isobutyr+MEK	0.00018	0.00064	—
16. Benzaldehyde	0.0000	0.0000	—
17. Hexanaldehyde	0.0000	0.0000	—
18. Methanol	0.4640	0.9470	—
19. Ethanol	0.0000	0.0000	—

* The RAF for M100 was unknown; thus, this value is uncorrected.

and scuffed cylinder wall and top piston ring in Cylinder 4. Lubricating oil left on the cylinder wall also undoubtedly contributed to the increased emissions. Incomplete combustion and detonation are also thought to have occurred in this cylinder as evidenced by the damaged spark plug and combustion product contamination. The pistons from Cylinders 3 and 5 also showed evidence of leakage past the top ring, which also contributed to increased emissions. To determine whether degraded catalyst performance also contributed to the increased emissions, the catalyst was removed from the vehicle and sent to Allied-Signal for analysis. At the time that this report was prepared, Allied-Signal had not completed their evaluation.

Fuel economy was measured during the FTP tests and highway economy was estimated during trips to and from San Antonio. FTP city mileage was measured to be 9.91 mpg (19 mpeg) during initial testing in January 1993 and 9.73 mpg (18.65 mpeg) during final testing in December 1994. This corresponds to a change of -1.8%. Highway mileage was estimated to be 16 mpg (31 mpeg). The highway fuel economy rating for the stock gasoline vehicle was 29 mpg. The relatively small change in city fuel economy could be due to test variability only and could have nothing to do with vehicle performance. No changes were made to the fuel-management control system during the program, and the O_2 exhaust sensor appeared to be operating properly during engine dynamometer testing; thus, if the vehicle fuel economy was actually reduced it was probably due to the degraded performance of Cylinder 4. Visual examination of the Cylinder 4 injector disclosed some discoloration and contaminate buildup, which may also have been due to the abnormal combustion process in this cylinder.

8. Oil Consumption Testing

The vehicle underwent initial oil consumption testing at SwRI in San Antonio. Initial tests were completed during March 1993 when the engine had logged about 1,500 miles. Additional oil consumption tests were completed during early 1995 after the vehicle had accumulated approximately 22,000 on-road miles. The SwRI oil consumption test reports are included in Appendices D and C. The initial test results reflect an oil consumption rate that is somewhat higher than typical gasoline-fueled vehicles that have been tested by SwRI. Data presented by Manni and Ciocci [3] also indicate that the initial oil consumption rate may have been higher than typical for gasoline fueled engines, especially at low engine speed. However, some of the data presented by Manni and Ciocci indicate oil consumption rates higher than those produced during the initial tests on the Corsica. In addition, Roberts [4] presents results from an Exxon test that correlate well with the initial Corsica test results. Thus, although the initial oil consumption results for the M100-fueled Corsica may be on the high end of the range for typical gasoline engines, the oil consumption was not exceptionally high. The initial oil consumption rate may have been affected by the lack of engine operating time before the test. The excellent results achieved during the emissions testing in January 1993 would reasonably have been expected to correlate with low oil consumption.

It was noted that there appeared to be a relationship between engine deceleration and increased oil consumption during the tests. The amount of valve lubricating oil drawn into the intake manifold may have increased with the greater manifold vacuum during deceleration. The SwRI report mentioned a relationship between high-temperature engine operation and increased oil consumption. Roberts [4] indicates that oil consumption is strongly related to both oil viscosity and oil volatility. Lower oil viscosity and higher oil volatility both promote higher oil consumption. The test oil used by SwRI was a 10W-30-grade oil with a viscosity of 9.85 cS at 100°C. This value of 100°C viscosity is on the lower end of the viscosity range of the oils used in the tests reported by Roberts [4].

The oil consumption tests run after the mileage accumulation showed significant increases in the oil consumption rates. Table 9 presents a summary comparison of the results from the two tests. The largest increase in the oil consumption rate was 123.6%, which was observed during steady-state operation at 2675 rpm. The increased oil consumption was almost certainly caused by the excessive scuffing and wear in Cylinder 4 and to a lesser extent by the wear in Cylinders 3 and 5. Moderate wear of the exhaust valve guides was noted earlier; however, there was no indication that the valve guide seals had deteriorated. Even the highest oil consumption rate reported by SwRI for the Corsica was only about 9% greater than oil consumption rates reported in reference [3] for gasoline engines. The condition of the engine at tear-down would indicate that the oil consumption should be even higher.

9. Conclusions

Long-term testing of the M100-fueled 1988 Corsica confirmed several reasonably well understood conditions and disclosed a few anomalies that may warrant further study. These are listed below:

A. It seems apparent that no off-the-shelf fuel pump is available that will provide reliable long-term service in M100. The problems appear to be primarily related to materials incompatibility with the fuel, but the lack of lubricity of M100 may also be factor contributing to fuel pump component wear. This lack of lubricity may have also been a factor in the (apparent) degraded performance of the injectors, which is thought to have led to detonation in Cylinders 3, 4, and 5. If M100 is to continue to be considered as an alternative fuel for the future, this problem needs to be investigated thoroughly.

B. Cold-starting is a severe problem when using M100 as a fuel below ambient temperatures of 15°C. Cold cranking of the Corsica is thought to have led to the degraded condition in Cylinders 3, 4, and 5, which contributed to combustion product buildup between the first and second piston rings in these cylinders and scoring of the cylinder wall and piston scuffing in Cylinder 4. An effective solution for this problem must be identified if M100 is to be a viable alternative fuel.

C. The results of the FTP emissions test at program initiation were excellent, with all exhaust constituents below ULEV levels except NMOG. Emissions at program conclusion were increased significantly as a result of the degraded condition of Cylinders 3, 4, and 5. Catalyst poisoning due to increased lubricating oil consumption may also have been a contributing factor. Allied Signal has agreed to evaluate the catalyst condition. The results of this evaluation will be forwarded to NREL when received.

D. Based on the results of this research, M100 is considered to have excellent potential as an alternative fuel. Cold-starting problems and component wear due to lack of lubricity will have to solved, but M100 has the potential for excellent emissions and, with a properly designed engine, provides outstanding vehicle performance and fuel economy. No fuel safety or handling problems were encountered during the project. The one case of fuel degradation (one 55-gallon drum) is thought to have been related to long-term storage in relatively poor environmental conditions. No other fuel quality problems were encountered during the project.

E. The initial oil consumption rates measured for the M100-fueled engine are on the upper end of the range typical of gasoline-fueled engines. The wear and damage experienced by the engine significantly affected the increase in the oil consumption rate.

10 References

1. Truman, R., D. Bretherton, B. Smith, R. Taeuber, M. Walser, and J. Jones, Texas Tech 1989 SAE Methanol Marathon Entry, 1989.
2. Walser, M., R. Taeuber, G. Bourn, M. Kasik, J. Jones, and T. Maxwell, Texas Tech 1990 SAE Methanol Challenge Entry, 1990.
3. Manni, M. and G. Ciocci, *An Experimental Study of Oil Consumption in Gasoline Engines*, SAE Paper No. 922374.
4. Roberts, D. C., *Section 4.7 Review of Oil Consumption Aspects of Engines*, **Engine Oils and Automotive Lubrication**, edited by Wilfried J. Bartz, Marcel Dekker, Inc., New York, 1993.

APPENDIX A
ECM Calibration Tables

Table F1 Main Spark Advance vs. LV8 - Load

Conversion Equation N = E * 256 / 90

400 rpm			600 rpm			800 rpm			1000 rpm			1200 rpm		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)
8011	63	22	801D	63	22	8029	63	22	8035	63	22	8041	63	22
8012	63	22	801E	63	22	802A	63	22	8036	63	22	8042	63	22
8013	63	22	801F	63	22	802B	63	22	8037	63	22	8043	63	22
8014	63	22	8020	63	22	802C	63	22	8038	63	22	8044	63	22
8015	63	22	8021	63	22	802D	63	22	8039	63	22	8045	63	22
8016	57	20	8022	57	20	802E	57	20	803A	57	20	8046	57	20
8017	51	18	8023	51	18	802F	51	18	803B	51	18	8047	51	18
8018	51	18	8024	51	18	8030	51	18	803C	51	18	8048	51	18
8019	51	18	8025	51	18	8031	51	18	803D	51	18	8049	51	18
801A	48	17	8026	48	17	8032	48	17	803E	48	17	804A	51	18
801B	43	15	8027	43	15	8033	43	15	803F	43	15	804B	46	16
801C	34	12	8028	34	12	8034	34	12	8040	34	12	804C	34	12

1400 rpm			1600 rpm			1800 rpm			2000 rpm			2200 rpm		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)
804D	65	23	8059	77	27	8065	77	27	8071	80	28	807D	80	28
804E	65	23	805A	80	28	8066	85	30	8072	91	32	807E	91	32
804F	65	23	805B	80	28	8067	85	30	8073	91	32	807F	91	32
8050	65	23	805C	80	28	8068	85	30	8074	91	32	8080	91	32
8051	65	23	805D	80	28	8069	85	30	8075	91	32	8081	91	32
8052	65	23	805E	80	28	806A	85	30	8076	91	32	8082	91	32
8053	65	23	805F	80	28	806B	82	29	8077	88	31	8083	91	32
8054	65	23	8060	80	28	806C	80	28	8078	85	30	8084	88	31
8055	65	23	8061	71	25	806D	74	26	8079	74	26	8085	80	28
8056	57	20	8062	65	23	806E	65	23	807A	65 (68)	23 (24)	8086	71	25
8057	46	16	8063	57	20	806F	57	20	807B	54 (60)	19 (21)	8087	54 (65)	19 (23)
8058	37	13	8064	41	14.4	8070	43	15	807C	40 (49)	14 (17.2)	8088	40 (52)	14 (18.3)

( ) Designates Original Value

Table F1 Main Spark Advance vs. LV8 - Load
(Continued)

2400 rpm			2800 rpm			3200 rpm			3600 rpm			4000 rpm		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)
8089	93	32.7	8095	85	30	80A1	85	30	80AD	85	30	80B9	85	30
808A	91	32	8096	94	33	80A2	94	33	80AE	91	32	80BA	91	32
808B	94	33	8097	94	33	80A3	94	33	80AF	91	32	80BB	91	32
808C	94	33	9098	94	33	80A4	94	33	80B0	88	31	80BC	85	30
808D	94	33	8099	94	33	80A5	88	31	80B1	85	30	80BD	82	29
808E	91	32	809A	91	32	80A6	88	31	80B2	82	29	80BE	82	29
808F	90	31.6	809B	88	31	80A7	85	30	80B3	82	29	80BF	82	29
8090	88	31	809C	88	31	80A8	85	30	80B4	82	29	80C0	82	29
8091	85	30	809D	85	30	80A9	82	29	80B5	80	28	80C1	82	29
8092	74	26	809E	74	26	80AA	74	26	80B6	74	26	80C2	80	28
8093	57 (65)	20 (23)	809F	57 (65)	20 (23)	80AB	63 (68)	22 (24)	80B7	65 (71)	23 (25)	80C3	68 (74)	24 (26)
8094	49 (57)	17.2 (20)	80A0	48 (56)	17 (19.7)	80AC	51 (56)	18 (19.7)	80B8	50 (53)	17.5 (18.6)	80C4	51 (56)	18 (19.7)

4400 rpm			4800 rpm			
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	LV8 - Load (for each series)
80C5	85	30	80D1	85	30	32
80C6	91	32	80D2	91	32	48
80C7	91	32	80D3	91	32	64
80C8	91	32	80D4	88	31	80
80C9	85	30	80D5	85	30	96
80CA	82	29	80D6	85	30	112
80CB	82	29	80D7	85	30	128
80CC	82	29	80D8	85	30	144
80CD	82	29	80D9	77	27	160
80CE	80	28	80DA	68	24	176
80CF	68 (74)	24 (26)	80DB	63 (68)	22 (24)	192
80D0	54 (60)	19 (21)	80DC	60 (66)	21 (23.2)	208

Main Spark Timing Calculation

Spark Advance = Main Spark Advance + Coolant Timing Bias
(deg. BTC) < Table F1> < Table F2 >

Spark Timing Range is 50 deg. BTC to 10 deg. ATC

Reference Pulse at 60 deg. BTC

( ) Designates Original Value

Table F2 Base Coolant Advance Correction vs. LV8 - Load

Conversion Equation N = (E + KCTBIAS) * 256 / 90

-16 deg. C			-4 deg. C			8 deg. C			20 deg. C			32 deg. C		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)
80EA	111	4	80F3	111	4	80FC	105	1.8	8105	83	-6	810E	89	-4
80EB	111	4	80F4	111	4	80FD	105	1.8	8106	83	-6	810F	89	-4
80EC	111	4	80F5	111	4	80FE	105	1.8	8107	83	-6	8110	89	-4
80ED	111	4	80F6	111	4	80FF	105	1.8	8108	83	-6	8111	89	-4
80EE	111	4	80F7	111	4	8100	105	1.8	8109	100	0	8112	100	0
80EF	114	5	80F8	114	5	8101	108	2.8	810A	100	0	8113	100	0
80F0	117	6	80F9	117	6	8102	111	4	810B	111	4	8114	105	1.8
80F1	119	6.7	80FA	119	6.7	8103	114	5	810C	114	5	8115	108	2.8
80F2	122	7.7	80FB	122	7.7	8104	117	6	810D	117	6	8116	111	4

44 deg. C			56 deg. C			68 deg. C			80 deg. C			92 deg. C		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)
8117	89	-4	8120	94	-2	8129	100	0	8132	100	0	813B	100	0
8118	89	-4	8121	94	-2	812A	100	0	8133	100	0	813C	100	0
8119	89	-4	8122	94	-2	812B	100	0	8134	100	0	813D	100	0
811A	89	-4	8123	94	-2	812C	100	0	8135	100	0	813E	100	0
811B	100	0	8124	100	0	812D	100	0	8136	100	0	813F	100	0
811C	100	0	8125	100	0	812E	100	0	8137	100	0	8140	100	0
811D	102	0.7	8126	100	0	812F	100	0	8138	100	0	8141	100	0
811E	102	0.7	8127	102	0.7	8130	100	0	8139	100	0	8142	100	0
811F	108	2.8	8128	105	1.8	8131	100	0	813A	100	0	8143	100	0

104 deg. C			116 deg. C			
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	LV8 -Load (for each series)
8144	100	0	814D	100	0	0
8145	100	0	814E	100	0	32
8146	100	0	814F	100	0	64
8147	100	0	8150	100	0	96
8148	100	0	8151	100	0	128
8149	100	0	8152	100	0	160
814A	100	0	8153	94	-2	192
814B	94	-2	8154	91	-3	224
814C	94	-2				256

Main Spark Timing Calculation

Spark Advance = Main Spark Advance + Coolant Timing Bias
(deg. BTC) < Table F1> < Table F2 >

Coolant Timing Bias : Function of Coolant Temp. and MAP

Table F200 OL (Open Loop) Base Pulse Inject vs. LV8 - Load and RPM

Conversion Equation N = E * 65.536 / 5

0 rpm			400 rpm			800 rpm			1200 rpm			1600 rpm		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (deg.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)
8815	0	0	8826	0	0	8837	0	0	8848	0	0	8859	0	0
8816	9 (13)	0.69 (1.0)	8827	9 (13)	0.69 (1.0)	8838	9 (13)	0.69 (1.0)	8849	9 (13)	0.69 (1.0)	885A	9 (13)	0.69 (1.0)
8817	16 (28)	1.22 (2.1)	8828	16 (28)	1.22 (2.1)	8839	16 (28)	1.22 (2.1)	884A	16 (28)	1.22 (2.1)	885B	16 (28)	1.22 (2.1)
8818	22 (45)	1.68 (3.4)	8829	22 (45)	1.68 (3.4)	883A	22 (45)	1.68 (3.4)	884B	22 (45)	1.68 (3.4)	885C	22 (45)	1.68 (3.4)
8819	49 (61)	3.74 (4.65)	882A	49 (61)	3.74 (4.65)	883B	49 (61)	3.74 (4.65)	884C	49 (61)	3.74 (4.65)	885D	49 (61)	3.74 (4.65)
881A	67 (77)	5.11 (5.9)	882B	67 (77)	5.11 (5.9)	883C	67 (77)	5.11 (5.9)	884D	67 (77)	5.11 (5.9)	885E	67 (77)	5.11 (5.9)
881B	81 (94)	6.18 (7.2)	882C	81 (94)	6.18 (7.2)	883D	81 (94)	6.18 (7.2)	884E	81 (94)	6.18 (7.2)	885F	81 (94)	6.18 (7.2)
881C	105 (110)	8.01 (8.4)	882D	105 (110)	8.01 (8.4)	883E	105 (110)	8.01 (8.4)	884F	105 (110)	8.01 (8.4)	8860	105 (110)	8.01 (8.4)
881D	118 (125)	9.0 (9.5)	882E	118 (125)	9.0 (9.5)	883F	118 (125)	9.0 (9.5)	8850	118 (125)	9.0 (9.5)	8861	118 (125)	9.0 (9.5)
881E	133 (141)	10.15 (10.8)	882F	133 (141)	10.15 (10.8)	8840	133 (141)	10.15 (10.8)	8851	133 (141)	10.15 (10.8)	8862	133 (141)	10.15 (10.8)
881F	155 (157)	11.83 (12)	8830	155 (157)	11.83 (12)	8841	155 (157)	11.83 (12)	8852	155 (157)	11.83 (12)	8863	155 (157)	11.83 (12)
8820	170 (172)	12.97 (13.1)	8831	170 (172)	12.97 (13.1)	8842	170 (172)	12.97 (13.1)	8853	170 (172)	12.97 (13.1)	8864	170 (172)	12.97 (13.1)
8821	188	14.34	8832	188	14.34	8843	188	14.34	8854	188	14.34	8865	188	14.34
8822	204	15.6	8833	204	15.6	8844	204	15.6	8855	204	15.6	8866	204	15.6
8823	219	16.7	8834	219	16.7	8845	219	16.7	8856	219	16.7	8867	219	16.7
8824	235	17.9	8835	235	17.9	8846	235	17.9	8857	235	17.9	8868	235	17.9
8825	251	19.15	8836	251	19.15	8847	251	19.15	8858	251	19.15	8869	251	19.15

2000 rpm			2400 rpm			2800 rpm			3200 rpm			3600 rpm		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)
886A	0	0	887B	0	0	888C	0	0	889D	0	0	88AE	0	0
886B	9 (13)	0.69 (1.0)	887C	9 (13)	0.69 (1.0)	888D	9 (13)	0.69 (1.0)	889E	9 (13)	0.69 (1.0)	88AF	9 (13)	0.69 (1.0)
886C	16 (28)	1.22 (2.1)	887D	16 (28)	1.22 (2.1)	888E	16 (28)	1.22 (2.1)	889F	16 (28)	1.22 (2.1)	88B0	16 (28)	1.22 (2.1)
886D	22 (45)	1.68 (3.4)	887E	22 (45)	1.68 (3.4)	888F	22 (45)	1.68 (3.4)	88A0	22 (45)	1.68 (3.4)	88B1	22 (45)	1.68 (3.4)
886E	49 (61)	3.74 (4.65)	887F	49 (61)	3.74 (4.65)	8890	49 (61)	3.74 (4.65)	88A1	49 (61)	3.74 (4.65)	88B2	49 (61)	3.74 (4.65)
886F	67 (77)	5.11 (5.9)	8880	67 (77)	5.11 (5.9)	8891	67 (77)	5.11 (5.9)	88A2	67 (77)	5.11 (5.9)	88B3	67 (77)	5.11 (5.9)
8870	81 (94)	6.18 (7.2)	8881	81 (94)	6.18 (7.2)	8892	81 (94)	6.18 (7.2)	88A3	81 (94)	6.18 (7.2)	88B4	81 (94)	6.18 (7.2)
8871	105 (110)	8.01 (8.4)	8882	105 (110)	8.01 (8.4)	8893	105 (110)	8.01 (8.4)	88A4	105 (110)	8.01 (8.4)	88B5	105 (110)	8.01 (8.4)
8872	118 (125)	9.0 (9.5)	8883	118 (125)	9.0 (9.5)	8894	118 (125)	9.0 (9.5)	88A5	118 (125)	9.0 (9.5)	88B6	118 (125)	9.0 (9.5)
8873	133 (141)	10.15 (10.8)	8884	133 (141)	10.15 (10.8)	8895	133 (141)	10.15 (10.8)	88A6	133 (141)	10.15 (10.8)	88B7	133 (141)	10.15 (10.8)
8874	155 (157)	11.83 (12)	8885	155 (157)	11.83 (12)	8896	155 (157)	11.83 (12)	88A7	155 (157)	11.83 (12)	88B8	155 (157)	11.83 (12)
8875	170 (172)	12.97 (13.1)	8886	170 (172)	12.97 (13.1)	8897	170 (172)	12.97 (13.1)	88A8	170 (172)	12.97 (13.1)	88B9	170 (172)	12.97 (13.1)
8876	188	14.34	8887	188	14.34	8898	188	14.34	88A9	188	14.34	88BA	188	14.34
8877	204	15.6	8888	204	15.6	8899	204	15.6	88AA	204	15.6	88BB	204	15.6
8878	219	16.7	8889	219	16.7	889A	219	16.7	88AB	219	16.7	88BC	219	16.7
8879	235	17.9	888A	235	17.9	889B	235	17.9	88AC	235	17.9	88BD	235	17.9
887A	251	19.15	888B	251	19.15	889C	251	19.15	88AD	251	19.15	88BE	251	19.15

Table F200 CL (Closed Loop) Base Pulse Inject vs. LV8 - Load

Conversion Equation N = E * 65.536 / 5

0 rpm			
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	LV8 Load
8815	0	0	0
8816	9 (13)	0.69 (1.0)	16
8817	16 (28)	1.22 (2.1)	32
8818	22 (45)	1.68 (3.4)	48
8819	49 (61)	3.74 (4.65)	64
881A	67 (77)	5.11 (5.9)	80
881B	81 (94)	6.18 (7.2)	96
881C	105 (110)	8.01 (8.4)	112
881D	118 (125)	9.0 (9.5)	128
881E	133 (141)	10.15 (10.8)	144
881F	155 (157)	11.83 (12)	160
8820	170 (172)	12.97 (13.1)	176
8821	188	14.34	192
8822	204	15.6	208
8823	219	16.7	224
8824	235	17.9	240
8825	251	19.15	256

Base Injection Pulse Width Calculation

BINJ = PW Table Value * [(A/F)closed loop / (A/F)desired)]
(Total PW/2) < Table F200 OL> < Table F50 >
or
<Table F200 CL>

(A/F)closed loop / (A/F)desired >= 1

Simultaneous Double Fire Injection: 1 Injection / Crankshaft Revolution

Delivered PW = BINJ [Adaptive Mode * Decel Mode + Accel Mult.] + CL Corr + Inj Corr

Table F91 LV8 -Load Accel Enrichment Multiplier vs. Coolant Temp
Conversion Equation N = E * 128

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	Coolant Temperature deg. C
876C	245 (96)	1.92 (0.75)	-40
876D	245 (92)	1.92 (0.72)	-28
876E	235 (88)	1.84 (0.69)	-16
876F	191 (72)	1.49 (0.56)	-4
8770	170 (64)	1.33 (0.5)	8
8771	150 (56)	1.17 (0.44)	20
8772	110 (40)	0.86 (0.31)	32
8773	98 (36)	0.77 (0.28)	44
8774	85 (32)	0.664 (0.25)	56
8775	45 (16)	0.35 (0.125)	68
8776	42 (16)	0.33 (0.125)	80
8777	18 (8)	0.14 (0.06)	92
8778	18 (8)	0.14 (0.06)	104
8779	18 (8)	0.14 (0.06)	116
877A	18 (8)	0.14 (0.06)	128

Acceleration Enrichment Multiplier Calculation

Delivered PW = BINJ [Adaptive Mode * Decel Mode + Accel Mult.] + CL Corr + Inj Corr
= BPINJ

BPINJ = BPINJ + (BPINJ) (AE FACTOR)

AE FACTOR = [(Load AE Mult. + Delta Throttle Pos. AE Mult.) - Limit] - Decay Rate
< Table F91 > < Table F102>

Additional fuel delivered 'synchronously' with base PW - based on rapid changes in measured air/cylinder

Table F102 Delta Throttle Accel Enrichment Multiplier vs. Coolant Temp
Conversion Equation N = E * 128

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	Coolant Temperature deg. C
846E	255 (144)	1.99 (1.125)	-40
846F	255 (144)	1.99 (1.125)	-28
8470	255 (128)	1.99 (1.0)	-16
8471	255 (124)	1.99 (0.97)	-4
8472	245 (118)	1.91(0.92)	8
8473	164 (80)	1.28 (0.625)	20
8474	130 (64)	1.02 (0.5)	32
8475	118 (56)	0.92 (0.44)	44
8476	92 (44)	0.72 (0.34)	56
8477	66 (32)	0.52 (0.25)	68
8478	50 (24)	0.39 (0.19)	80
8479	17 (10)	0.13 (0.08)	92
847A	17 (10)	0.13 (0.08)	104
847B	17 (10)	0.13 (0.08)	116
847C	17 (10)	0.13 (0.08)	128

Acceleration Enrichment Multiplier Calculation

Delivered PW = BINJ [Adaptive Mode * Decel Mode + Accel Mult.] + CL Corr + Inj Corr
= BPINJ

BPINJ = BPINJ + (BPINJ) (AE FACTOR)

AE FACTOR = [(Load AE Mult. + Delta Throttle Pos. AE Mult.) - Limit] - Decay Rate
< Table F91 > < Table F102>

Additional fuel delivered 'asynchronously' with base PW - based on rapid changes in measured throttle position (TPS)

Table F50 Cold Engine F/A % Chng vs. LV8 - Load and CLDEGFLT

*Conversion Equation N = % Change * 2.56*

-28 deg. C			-4 deg. C			20 deg. C			44 deg. C			68 deg. C		
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)
85D9	33 (36)	13 (14)	85EA	31 (34)	12.3 (13.3)	85FB	33 (36)	13 (14)	860C	12 (13)	4.5 (5)	861D	0	0
85DA	33 (36)	13 (14)	85EB	31 (34)	12.3 (13.3)	85FC	33 (36)	13 (14)	860D	29 (32)	11.5 (12.5)	861E	0	0
85DB	33 (36)	13 (14)	85EC	31 (34)	12.3 (13.3)	85FD	33 (36)	13 (14)	860E	31 (34)	12.3 (13.3)	861F	13	5
85DC	33 (36)	13 (14)	85ED	31 (34)	12.3 (13.3)	85FE	33 (36)	13 (14)	860F	31 (34)	12.3 (13.3)	8620	26	10
85DD	36 (38)	14 (15)	85EE	33 (36)	13 (14)	85FF	33 (36)	13 (14)	8610	31 (34)	12.3 (13.3)	8621	36	14
85DE	37 (40)	14.6 (15.6)	85EF	36 (38)	14 (15)	8600	36 (38)	14 (15)	8611	33 (36)	13 (14)	8622	37	14.4
85DF	39 (42)	15.4 (16.4)	85F0	37 (40)	14.6 (15.6)	8601	36 (39)	14.2 (15.2)	8612	36 (38)	14 (15)	8623	38	15
85E0	46 (48)	17.8 (18.8)	85F1	44 (46)	17 (18)	8602	41 (44)	16 (17)	8613	37 (40)	14.6 (15.6)	8624	40	15.6
85 E1	47 (50)	18.5 (19.5)	85F2	46 (48)	17.8 (18.8)	8603	46 (48)	17.8 (18.8)	8614	39 (42)	15.4 (16.4)	8625	41	16
85 E2	51 (54)	20 (21)	85F3	49 (52)	19.3 (20.3)	8604	47 (50)	18.5 (19.5)	8615	41 (44)	16 (17)	8626	42	16.4
85 E3	55 (57)	21.3 (22.3)	85F4	54 (56)	21 (22)	8605	49 (52)	19.3 (20.3)	8616	47 (50)	18.5 (19.5)	8627	43	16.8
85 E4	56 (59)	22 (23)	85F5	56 (58)	21.7 (22.7)	8606	51 (54)	20 (21)	8617	49 (52)	19.3 (20.3)	8628	44	17
85 E5	59 (61)	23 (24)	85F6	57 (60)	22.4 (23.4)	8607	54 (56)	21 (22)	8618	51 (54)	20 (21)	8629	44	17
85 E6	59 (61)	23 (24)	85F7	57 (60)	22.4 (23.4)	8608	56 (58)	21.7 (22.7)	8619	51 (54)	20 (21)	862A	44	17
85 E7	59 (61)	23 (24)	85F8	57 (60)	22.4 (23.4)	8609	56 (58)	21.7 (22.7)	861A	51 (54)	20 (21)	862B	44	17
85 E8	59 (61)	23 (24)	85F9	57 (60)	22.4 (23.4)	860A	56 (58)	21.7 (22.7)	861B	51 (54)	20 (21)	862C	44	17
85 E9	59 (61)	23 (24)	85FA	57 (60)	22.4 (23.4)	860B	56 (58)	21.7 (22.7)	861C	51 (54)	20 (21)	862D	44	17

92 deg. C			116 deg. C				
16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)		LV8 -Load (for each series)
862E	0	0	863F	0	0		0
862F	0	0	8640	0	0		16
8630	13	5	8641	13	5		32
8631	26	10	8642	26	10		48
8632	36	14	8643	36	14		64
8633	37	14.4	8644	37	14.4		80
8634	38	15	8645	38	15		96
8635	39	15.2	8646	38	15		112
8636	40	15.6	8647	38	15		128
8637	40	15.6	8648	38	15		144
8638	40	15.6	8649	38	15		160
8639	40	15.6	864A	38	15		176
863A	40	15.6	864B	38	15		192
863B	40	15.6	864C	38	15		208
863C	40	15.6	864D	38	15		224
863D	40	15.6	864E	38	15		240
863E	40	15.6	864F	38	15		256

Open Loop F/A Calculation

Open Loop F/A = C.L. F/A [(%Enrich.) + (%Enrich. Time-Out) + (Add. Mode)]
< Table F50 >   < Table F51>

%Enrich. Time-Out ---> 0 by a predetermined exp. decay function

%Enrichment ---> 1 at point where closed loop switches

Table F51 Time Out F/A % Chng Init Value vs. Coolant Temp

Conversion Equation N = % Change * 1.28

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (% Chng.)	Coolant Temperature deg. C
8650	150 (160)	117.2 (125)	-40
8651	150 (160)	117.2 (125)	-28
8652	128 (139)	100 (108.6)	-16
8653	100 (112)	78 (87.5)	-4
8654	49 (56)	38 (44)	8
8655	35 (42)	27 (33)	20
8656	23 (28)	18 (22)	32
8657	18 (22)	14 (17)	44
8658	13 (16)	10 (12.5)	56
8659	13 (16)	10 (12.5)	68
865A	13 (16)	10 (12.5)	80
865B	11 (14)	8.6 (11)	92
865C	11 (14)	8.6 (11)	104
865D	11 (14)	8.6 (11)	116

Open Loop F/A Calculation

Open Loop F/A = C.L. F/A [(%Enrich.) + (%Enrich. Time-Out) + (Add. Mode)]
< Table F50 > < Table F51>

Closed Loop F/A Calculation

Closed Loop F/A = C.L. Stoich F/A [1 + (%Enrich. Time-Out)]
< Table F51 >

%Enrich. Time-Out ---> 0 by a predetermined exp. decay function

Table F64 Crank Fuel PW vs. Coolant Temperature

Conversion Equation N = E * 256 / KSCAL64

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	Coolant Temperature deg. C
86 E6	163 (179)	119 (131)	-40
86 E7	156 (172)	114 (126)	-28
86 E8	135 (148)	99 (108.4)	-16
86 E9	96 (105)	70 (77)	-4
86 EA	78 (86)	57 (63)	8
86 EB	45 (48)	33 (36)	20
86 EC	37 (40)	27 (29)	32
86 ED	30 (33)	22 (24)	44
86 EE	19 (21)	14 (15.4)	56
86 EF	16 (18)	12 (13)	68
86F0	14 (16)	10 (12)	80
86F1	14 (16)	10 (12)	92
86F2	14 (16)	10 (12)	104
86F3	17 (19)	12.5 (14)	116

Cranking Fuel Pulse Width Calculation

Crank PW / Rev = (Crank PW) (Crank PW Time - Out) (Constant)
< Table F64 > < Table F65>

Crank PW - Duration per crank revolution (1/2 total fuel / cylinder)

At <450 rpm and <95 deg. F - 1/3 Crank PW injected 3 times per revolution

Table F65 Crank Fuel PW Multiplier vs. Reference Pulses

Conversion Equation N = E * 256

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (msec.)	Crank Reference Pulses
86F4	170 (192)	0.66 (0.75)	0
86F5	105 (128)	0.41 (0.5)	8
86F6	105 (128)	0.41 (0.5)	16
86F7	105 (128)	0.41 (0.5)	24
86F8	105 (128)	0.41 (0.5)	32
86F9	105 (128)	0.41 (0.5)	40
86FA	105 (128)	0.41 (0.5)	48
86FB	105 (128)	0.41 (0.5)	56
86FC	105 (128)	0.41 (0.5)	64
86FD	105 (128)	0.41 (0.5)	72
86FE	105 (128)	0.41 (0.5)	80
86FF	105 (128)	0.41 (0.5)	88
8700	105 (128)	0.41 (0.5)	96
8701	105 (128)	0.41 (0.5)	104
8702	105 (128)	0.41 (0.5)	112
8703	105 (128)	0.41 (0.5)	120
8704	105 (128)	0.41 (0.5)	128

Cranking Fuel Pulse Width Calculation

Crank PW / Rev = (Crank PW) (Crank PW Time - Out) (Constant)
< Table F64 > < Table F65>

Crank PW Time-Out - Crank PW Multiplier

At <450 rpm and <95 deg. F - 1/3 Crank PW injected 3 times per revolution

3 Reference pulses per revolution

Table F17 Idle Air Control (IAC) Command Speed vs. Coolant Temp

Conversion Equation N = E / 12.5

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (rpm)	Coolant Temperature deg. C
8957	136	1700	-40
8958	128	1600	-28
8959	112	1400	-16
895A	104	1300	-4
895B	104	1300	8
895C	96	1200	20
895D	96	1200	32
895E	80	1000	44
895F	72	900	56
8960	72 (70)	900 (875)	68
8961	72 (68)	900 (850)	80
8962	72 (68)	900 (850)	92
8963	72 (68)	900 (850)	104
8964	72 (69)	900 (863)	116
8965	72 (70)	900 (875)	128
8966	72	900	140
8967	72	900	152

IAC Command Speed Calculation

Command Idle RPM = Base Idle RPM + RPM Offset
< Table F17 >

Four Modes of Operation

Start-up Delay - IAC motor initially moved to 'warm park' position

Open Loop - IAC motor retracts until actual rpm equals desired rpm

Closed Loop - IAC motor regulates to achieve desired rpm

Throttle/Load Compensation - IAC motor compensates idle speed for applied loads (A/C, Pwr Steering, etc.)

Table F76 EGR Duty Cycle vs. LV8 - Load and RPM

Conversion Equation N = E * 256

800 RPM			1000 RPM			1200 RPM			1400 RPM			1600 RPM		
16 Bit Hexdecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexdecimal Address	Decimal Computer Unit	Engineering Unit (DC %)
830B	0	0	8314	0	0	831D	0	0	8326	0	0	832F	0	0
830C	0	0	8315	0	0	831E	0	0	8327	0	0	8330	0	0
830D	0	0	8316	0	0	831F	0	0	8328	0	0	8331	30 (26)	11.7 (10)
830E	0	0	8317	15 (13)	5.9 (5)	8320	43 (38)	16.8 (15)	8329	74 (64)	28.9 (25)	8332	103 (90)	40.2 (35)
830F	0	0	8318	30 (26)	11.7 (10)	8321	58 (51)	22.7 (20)	832A	103 (90)	40.2 (35)	8333	132 (115)	51.6 (45)
8310	0	0	8319	43 (38)	16.8 (15)	8322	74 (64)	28.9 (25)	832B	117 (102)	45.7 (40)	8334	147 (128)	57.4 (50)
8311	0	0	831A	58 (51)	22.7 (20)	8323	88 (77)	34.4 (30)	832C	132 (115)	51.6 (45)	8335	162 (141)	63.3 (55)
8312	0	0	831B	74 (64)	28.9 (25)	8324	103 (90)	40.2 (35)	832D	147 (128)	57.4 (50)	8336	168 (146)	65.6 (57)
8313	0	0	831C	88 (77)	34.4 (30)	8325	103 (90)	40.2 (35)	832E	162 (141)	63.3 (55)	8337	177 (154)	69.1 (60)

1800 RPM			2000 RPM			2200 RPM			2400 RPM			2600 RPM		
16 Bit Hexdecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexdecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexdecimal Address	Decimal Computer Unit	Engineering Unit (DC %)
8338	0	0	8341	0	0	834A	0	0	8353	0	0	835C	0	0
8339	0	0	8342	0	0	834B	0	0	8354	0	0	835D	0	0
833A	43 (38)	16.8 (15)	8343	58 (51)	22.7 (20)	834C	43 (38)	16.8 (15)	8355	30 (26)	11.7 (10)	835E	0	0
833B	103 (90)	40.2 (35)	8344	103 (90)	40.2 (35)	834D	103 (90)	40.2 (35)	8356	88 (77)	34.4 (30)	835F	74 (64)	28.9 (25)
833C	132 (115)	51.6 (45)	8345	132 (115)	51.6 (45)	834E	147 (128)	51.6 (45)	8357	132 (115)	51.6 (45)	8360	117 (102)	45.7 (40)
833D	147 (128)	57.4 (50)	8346	147 (128)	57.4 (50)	834F	162 (141)	57.4 (50)	8358	147 (128)	51.6 (45)	8361	147 (128)	57.4 (50)
833E	177 (154)	69.1 (60)	8347	177 (154)	69.1 (60)	8350	177 (154)	69.1 (60)	8359	177 (154)	69.1 (60)	8362	177 (154)	69.1 (60)
833F	185 (161)	72.3 (63)	8348	190 (166)	74.2 (65)	8351	190 (166)	74.2 (65)	835A	190 (166)	74.2 (65)	8363	190 (166)	74.2 (65)
8340	190 (166)	74.2 (65)	8349	205 (179)	80.1 (70)	8352	205 (179)	80.1 (70)	835B	190 (166)	74.2 (65)	8364	190 (166)	74.2 (65)

2800 RPM			3000 RPM				
16 Bit Hexdecimal Address	Decimal Computer Unit	Engineering Unit (DC %)	16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (DC %)		LV8 -Load (for each series)
8365	0	0	836E	0	0		32
8366	0	0	836F	0	0		48
8367	0	0	8370	0	0		64
8368	74 (64)	28.9 (25)	8371	74 (64)	28.9 (25)		80
8369	117 (102)	45.7 (40)	8372	117 (102)	45.7 (40)		96
836A	147 (128)	57.4 (50)	8373	147 (128)	57.4 (50)		112
836B	177 (154)	69.1 (60)	8374	177 (154)	69.1 (60)		128
836C	190 (166)	74.2 (65)	8375	190 (166)	74.2 (65)		144
836D	190 (166)	74.2 (65)	8376	190 (166)	74.2 (65)		160

EGR Duty Cycle Calculation

EGR DC = (EGR Base DC) (EGR DC Coolant Mult)
< Table F76 > < Table F77 >

EVRV DC	EGR Valve Press.	EGR Valve Pos
0%	atm.	closed (normally)
0 < DC < 100%	~ 10 - 24 kPa	variable lift
100%	man. vacuum	fully open

EVRV - Electronic Vacuum Regulator Valve

Table F77 EGR Duty Cycle Multiplier vs. Coolant Temp

Conversion Equation N = E * 128

16 Bit Hexidecimal Address	Decimal Computer Unit	Engineering Unit (gain)	Coolant Temperature deg. C
8377	0	0	-40
8378	35 (32)	0.27 (0.25)	-28
8379	85 (80)	0.66 (0.625)	-16
837A	125 (120)	0.98 (0.94)	-4
837B	158 (152)	1.23 (1.19)	8
837C	170 (168)	1.33 (1.31)	20

EGR Duty Cycle Calculation

EGR DC = (EGR Base DC) (EGR DC Coolant Mult)
< Table F76 > < Table F77 >

EGR DC = 0 when:

- park / nuetral
- manifold air temp. (MAT) < -40 deg. C
- throttle position (TPS) < 2.7%, if not currently equal to zero
- throttle position (TPS) < 4.3%, if currently equal to zero
- power enrichment mode enabled - TPS > 60% engine warmed

APPENDIX B

Oil Sample Test Reports

TEXAS TECH UNIVERSITY
ATTN: DR. TIM MAXWELL
P.O. BOX 41021
LUBBUCK , TX, 79409

MONITORED MAINTENANCE
Lube Oil Analysis Program
TEST REPORT

Atlanta, GA
(404) 279-1370

Unit No: LIC#577-492
Company: MECH ENGINEERING
Location: LUBBOCK TX
Component: ENGINE
Make & Model: CHEVY N/G
Oil Capacity: 4 QTS.
Oil Type: LUBRIZOIL

SAMPLE INFORMATION		COMMENTS
3 NO. 1-	009225920	DIRT (SILICON) PROBABLY ASSEMBLY CONTAMINATION. # SUSPECT BREAK-IN MATERIAL. CHANGE OIL AND FILTER – IF NOT DONE AT TIME OF SAMPLING. (EVALUATOR-RALPH PIKE).
nple Drawn:	N/G	
ort Date:	09/24/93	
HR Unit:	13,450	
HR Oil:	N/G	
Added:		
NO. 2-		–
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
NO. 3-		–
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
NO. 4-		–
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
NO. 5-		–
nple Drawn:		
ort Date:		
IR Unit:		
IR Oil:		
Added:		
NO. 6-		–
nple Drawn:		
ort Date:		
IR Unit:		
IR Oil:		
Added:		

PHYSICAL DATA								ELEMENTAL CONCENTRATIONS IN PARTS PER MILLION (PPM) BY WEIGHT																
S .00 C ST	WATER % Vol	FUEL % Vol	SOLIDS % Vol	FUELSOOT % Wt	OXIDATION A/cm	NITRATION A/cm		SILICON	IRON	CHROMIUM	MOLYBDENUM	NICKEL	ALUMINUM	TIN	COPPER	LEAD	SILVER	SODIUM	BORON	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC
10.4	<.05	---	<.1		7	12		138 £	156	9	1	3	7	69 #	47 #	40	0	85	1	2152	137	0	1009	2458

TEXAS TECH UNIVERSITY
ATTN: DR. TIM MAXWELL
P.O. BOX 41021

LUBBUCK TX 79409

Computer-Code--> 041591 '88 CORSICA

CONOCO MONITORED MAINTENANCE
Lube Oil Analysis Program

TEST REPORT

Atlanta, GA
(404) 454-8000

Unit No:	'88 CORSICA
Company:	TEXAS TECH UNIVERSITY
Location:	LUBBOCK TX
Component:	ENGINE
Make & Model:	CHEVY N/G
Oil Capacity:	N/G
Oil Type:	

SAMPLE INFORMATION		COMMENTS
LAB NO. 1-	E07070247	SPECIFICATIONS FOR THIS OIL ARE NOT AVAILABLE. TRACE WATER DETECTED. NO GLYCOL DETECTED. SUSPECT CONDENSATE. SUSPECT SILICON IS FROM ENGINE SEALANT (GASKET MATERIAL). SUSPECT ABNORMAL CYLINDER AREA WEAR. CHECK FOR POWER LOSS, BLOW-BY, SMOKING, OIL CONSUMPTION, ETC. CHANGE OIL AND FILTER IF NOT DONE AT TIME OF SAMPLING. RESAMPLE AT NORMAL INTERVAL. [# VISCOSITY APPEARS LOWER THAN USUAL FOR MOTOR OIL.]
Sample Drawn	06/30/94	
Report Date:	07/11/94	
MI/HR Unit:	19457	
MI/HR Oil:	3000	
Oil Added:	NORMAL	
LAB NO. 2-	E09269705	NOTE VISCOSITY. (LOW). INSPECT FUEL SYSTEM FOR DEFECTS. TELECON. (EVALUATOR-MIKE COSTELLO) PER DR. TIM MAXWELL: UNIT HAS HAD PROBLEMS WITH FUEL PUMP. FUEL IS 100% METHANOL.
Sample Drawn:	09/20/94	
Report Date:	09/29/94	
MI/HR Unit:	27000	
MI/HR Oil:	7000	
Oil Added:	NORMAL	
LAB NO. 3-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 4-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 5-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 6-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		

	PHYSICAL DATA								ELEMENTAL CONCENTRATIONS IN PARTS PER MILLION (PPM) BY WEIGHT															
LAB NO	VIS 100C cSt	WATER % Vol	FUEL % Vol	SOLIDS % Vol	FUELSOOT % Wt	OXIDATION A/cm	NITRATION A/cm		SILICON	IRON	CHROMIUM	MOLYBDENUM	NICKEL	ALUMINUM	TIN	COPPER	LEAD	SILVER	SODIUM	BORON	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS
1	8.1	0.2		<.1		0	0		44 B	293 B	21	1	7	9	11	60 B	35	0	41	[illegible]	1118	40	0	89
2	7.8	<.05		<.1		0	0		19	80	5	13	3	8	0	4	20	0	68	36	855	1167	0	12
3																								
4																								
5																								
6																								

TEXAS TECH UNIVERSITY
ATTN: DR. TIM MAXWELL
P.O. BOX 41021
LUBBUCK , TX, 79409

CONOCO MONITORED MAINTENANCE
Lube Oil Analysis Program

TEST REPORT

Atlanta, GA
(404) 454-8000

Unit No: '88 CORSICA
Company: TEXAS TECH UNIVERSITY
Location: LUBBOCK TX
Component: ENGINE
Make & Model: CHEVY N/G
Oil Capacity:
Oil Type: LUBRIZOL OS#796164

SAMPLE INFORMATION		COMMENTS
3 NO. 1-	E07070247	SPECIFICATIONS FOR THIS OIL ARE NOT AVAILABLE. TRACE WATER DETECTED. NO GLYCOL DETECTED. SUSPECT CONDENSATE. SUSPECT SILICON IS FROM SEALANT MATERIAL (GASKETS). SUSPECT ABNORMAL CYLINDER AREA WEAR. CHECK FOR POWER LOSS, BLOW-BY, SMOKING, OIL CONSUMPTION, ETC. CHANGE OIL AND FILTER IF NOT DONE AT TIME OF SAMPLING. RESAMPLE AT NORMAL INTERVAL. (EVALUATOR - G.D.) # VISCOSITY APPEARS LOWER THAN USUAL FOR MOTOR OIL.
nple Drawn:	06/30/94	
ort Date:	07/11/94	
HR Unit:	19,457	
HR Oil:	3,000	
Added:	NORMAL	
3 NO 2-		
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
3 NO. 3-		
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
NO. 4-		
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
NO. 5-		
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		
NO. 6-		
nple Drawn:		
ort Date:		
HR Unit:		
HR Oil:		
Added:		

PHYSICAL DATA							ELEMENTAL CONCENTRATIONS IN PARTS PER MILLION (PPM) BY WEIGHT																
S 0 C T	WATER % Vol	FUEL % Vol	SOLIDS % Vol	FUELSOOT % Wt	OXIDATION A/cm	NITRATION A/cm	SILICON	IRON	CHROMIUM	MOLYBDENUM	NICKEL	ALUMINUM	TIN	COPPER	LEAD	SILVER	SODIUM	BORON	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC
.1	0.2	---	<.1		---	---	44 B	292 B	21	0	6	8	11	60 B	35	0	40	0	1118	39	0	898	2181

TEXAS TECH UNIVERSITY
ATTN: DR. TIM MAXWELL
P.O. BOX 41021

LUBBUCK TX 79409
Computer-Code--> 041591 123583

CONOCO MONITORED MAINTENANCE
Lube Oil Analysis Program

TEST REPORT

Atlanta, GA
(404) 454-8000

Unit No: 123583 E
Company: TEXAS TECH UNIVERSIT
Location:
Component: ENGINE
Make & Model: N/G N/G
Oil Capacity: N/G
Oil Type:

SAMPLE INFORMATION		COMMENTS
LAB NO. 1-	E11281272	INSUFFICIENT INFO GIVEN TO PROVIDE ACCURATE EVALUATION OF DATA. SUSPECT ABNORMAL CYLINDER AREA WEAR. SUSPECT RING WEAR. VALVE AREA WEAR INDICATED (NICKEL). CHECK FOR POWER LOSS, BLOW-BY, SMOKING, OIL CONSUMPTION, ETC. SUSPECT ABNORMAL MAIN/CONN. ROD BEARING WEAR. WEAR NOT MAJOR, BUT SHOULD BE NOTED. CHECK FOR KNOCKING AND/OR LOSS OF OIL PRESSURE. RECOMMEND CLOSE MONITORING. RESAMPLE AT ONE HALF NORMAL INTERVAL. (EVALUATOR - G.D.)
Sample Drawn:	11/18/94	
Report Date:	12/02/94	
MI/HR Unit:	31000	
MI/HR Oil:	3500	
Oil Added:	NORMAL	
LAB NO. 2-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 3-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 4-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 5-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		
LAB NO. 6-		
Sample Drawn:		
Report Date:		
MI/HR Unit:		
MI/HR Oil:		
Oil Added:		

	PHYSICAL DATA								ELEMENTAL CONCENTRATIONS IN PARTS PER MILLION (PPM) BY WEIGHT															
LAB NO	VIS 100C cSt	WATER % Vol	FUEL % Vol	SOLIDS % Vol	FUELSOOT % Wt	OXIDATION A/cm	NITRATION A/cm	TAN	SILICON	IRON	CHROMIUM	MOLYBDENUM	NICKEL	ALUMINUM	TIN	COPPER	LEAD	SILVER	SODIUM	BORON	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS
1	8.5	<.05		0.1		0	0	3.1	19	214 C	17 B	2	11 B	7	7	32 B	34 B	0	25	0	1832	32	0	113
2																								
3																								
4																								
5																								
6																								

TEXAS TECH UNIVERSITY
ATTN: DR TIM MAXWELL
P.O. BOX 41021
LUBBUCK , TX, 79409

CONOCO MONITORED MAINTENANCE
Lube Oil Analysis Program

TEST REPORT

Atlanta, GA
(404) 454-8000

Unit No: 4
Company: TEXAS TECH UNIVERSITY
Location: LUBBOCK TX
Component: ENGINE
Make & Model: CHEVY N/G
Oil Capacity: 5 QTS.
Oil Type: LUBRIZOL

SAMPLE INFORMATION	COMMENTS
NO. 1- 010019921 ple Drawn: 09/24/93 ort Date: 10/06/93 R Unit: 17,177 R Oil: 3,727 dded:	OIL MFG., TRADENAME, AND/OR SAE/ISO GRADE OF OIL NOT GIVEN. HIGH LEVEL OF DIRT DETECTED. GENERALIZED (NON-SPECIFIC) WEAR INDICATED. CHANGE OIL AND FILTER IF NOT DONE AT TIME OF SAMPLING. (EVALUATOR-RALPH PINE).
NO 2- ple Drawn: ort Date: R Unit: R Oil: dded:	
NO. 3- ple Drawn: ort Date: R Unit: R Oil: dded:	
NO. 4- ple Drawn: ort Date: R Unit: R Oil: dded:	
NO. 5- ple Drawn: ort Date: R Unit: R Oil: dded:	
NO. 6- ple Drawn: ort Date: R Unit: R Oil: dded:	

PHYSICAL DATA								ELEMENTAL CONCENTRATIONS IN PARTS PER MILLION (PPM) BY WEIGHT																	
00 C ST	WATER % Vol	FUEL % Vol	SOLIDS % Vol	FUELSOOT % Wt	OXIDATION A/cm	NITRATION A/cm		SILICON	IRON	CHROMIUM	MOLYBDENUM	NICKEL	ALUMINUM	TIN	COPPER	LEAD	SILVER	SODIUM	BORON	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC
3.5	<.05	---	<.1		8	12		98 E	207 E	31 E	2	3	9	30 E	47	27	0	47	0	2060	57	0	1072	2157

APPENDIX C

Emissions Test Results from Southwest Research Institute

FAX COVER LETTER

DATE: 02/22/93

PLEASE DELIVER TO: Mr. Jesse Jones

FAX NUMBER: 806-742-3540

FROM: Kevin Whitney, Phone: 210-522-5869 SwRI CHARGE NO. 08#

Southwest Research Institute
Department of Emissions Research
Automotive Products and Emissions Research Division
Fax Number (512) 522-3950

WE ARE TRANSMITTING 5 PAGES (including this cover page)

If transmission is not complete, please call (512) 522-2609

MESSAGE:

Dear Jesse:

Here a new copies of the data, the are no changes but they're a bit easier to read. The reason the values for NMOG and THC are similar is because of how each is calculated. The calculations are as follows:

NMOG = NMHC + CARBONYL + ALCOHOL
THC = NMOG + 0.0043*CH4

As you can see, for CARB calculation purposes THC is a calculated number rather than from a FID analyser. This is how the confusion arose. Please note that this data does not have a RAF applied to it. It is 0.41 for M85, but I'm not sure what it is for M100. If you have any other questions, feel free to call me at 210-522-5869.

Sincerely,

Kevin A. Whitney
Engineer
Department of Emissions Research

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                     SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
   COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                            TEST CC-TT-01                     METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA               DATE  1/19/93     RUN             FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6            DYNO  2      BAG CART  2        - H .126  C .375  O .499  X .000
TRANSMISSION    5M                             ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)       TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.30 IN HG (744.2 MM HG)     DRY BULB TEMPERATURE  72.0°F ( 22.2°C)        NOX HUMIDITY C.F.   .880
RELATIVE HUMIDITY 38.6 PCT.
 BAG NUMBER                                        1                  2                   3
 BAG DESCRIPTION                          COLD TRANSIENT         STABILIZED          HOT TRANSIENT
                                          ( 0-505 SEC.)       (505-1372 SEC.)       ( 0- 505 SEC.)
 RUN TIME SECONDS                              505.2               867.0               505.4
 DRY/WET CORRECTION FACTOR, SAMP/BACK        .977/.989           .980/.989           .978/.989
 MEASURED DISTANCE MILES (KM)               3.58 ( 5.76)        3.83 ( 6.16)        3.57 ( 5.74)
 BLOWER FLOW RATE SCFM (SCMM)              557.2 (15.78)       556.9 (15.77)       556.5 (15.76)
 GAS METER FLOW RATE SCFM (SCMM)            .27 (  .01)         .27 (  .01)         .27 (  .01)
 TOTAL FLOW SCF (SCM)                     4694. ( 132.9)      8051. ( 228.0)      4689. ( 132.8)

 HC  SAMPLE METER/RANGE/PPM (BAG)         37.8/  2/ 37.78     11.9/  2/ 11.89     11.5/  2/ 11.49
 HC  BCKGRD METER/RANGE/PPM                7.6/  2/  7.60      9.9/  2/  9.89      9.7/  2/  9.69
 CO  SAMPLE METER/RANGE/PPM               33.6/ 12/ 32.60     17.1/ 12/ 16.47     10.6/ 12/ 10.16
 CO  BCKGRD METER/RANGE/PPM                1.1/ 12/  1.04      1.4/ 12/  1.33      1.3/ 12/  1.23
 CO2 SAMPLE METER/RANGE/PCT               77.8/ 14/ .6203     67.4/ 14/ .4640     74.1/ 14/ .5601
 CO2 BCKGRD METER/RANGE/PCT               14.0/ 14/ .0478     13.7/ 14/ .0466     13.8/ 14/ .0470
 NOX SAMPLE METER/RANGE/PPM (BAG) (D)     45.8/  1/ 11.43      2.7/  1/   .68     27.0/  1/  6.77
 NOX BCKGRD METER/RANGE/PPM                1.5/  1/   .38      1.9/  1/   .48      1.1/  1/   .28
 CH4 SAMPLE PPM (1.120)                          4.29                3.55                4.39
 CH4 BCKGRD PPM                                  2.54                2.52                2.51

 DILUTION FACTOR                                18.42               24.78               20.57
 HC   CONCENTRATION PPM                         30.59                2.40                2.27
 CO   CONCENTRATION PPM                         30.61               14.77                8.70
 CO2  CONCENTRATION PCT                         .5751               .4193               .5154
 NOX  CONCENTRATION PPM                         11.07                 .22                6.51
 CH4  CONCENTRATION PPM                          1.88                1.13                2.00
 NMHC CONCENTRATION PPM                           .13                1.07                 .02

 THC     MASS GRAMS                             6.521                .365                .189
 CO      MASS GRAMS                             4.737               3.920               1.345
 CO2     MASS GRAMS                           1399.64             1750.06             1253.19
 NOX     MASS GRAMS                             2.478                .085               1.454
 CH4     MASS GRAMS                              .167                .172                .178
 NMHC    MASS GRAMS (FID)                        .010                .141                .001
 FUEL    MASS KG                                1.031               1.279                .914
 FUEL ECONOMY MPG (L/100KM)               10.43 ( 22.55)      8.98 ( 26.18)      11.71 ( 20.08)

3-BAG COMPOSITE RESULTS

              THC      G/MI          .40                 CH4       G/MI         .047
              CO       G/MI          .91                 NMHC      G/MI         .020
              NOX      G/MI          .27                 CARBONYL  G/MI         .009
                                                         ALCOHOL   G/MI         .367
              FUEL ECONOMY MPG (L/100KM)     9.91 (23.73)      NMOG      G/MI         .396
```

CARTER MIR
818 575

ANNETTE
GUERRE

3.12 GR

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                      SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
   COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                           TEST CC-TT-01                          METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA              DATE  1/19/93     RUN                  FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6           DYNO  2       BAG CART  2              H .126  C .375  O .499  X .000
TRANSMISSION    5M                            ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)      TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.30 IN HG (744.2 MM HG)     DRY BULB TEMPERATURE  72.0°F ( 22.2°C)       NOX HUMIDITY C.F.  .880
RELATIVE HUMIDITY 38.6 PCT.
  BAG NUMBER                1                    2                    3
  BAG DESCRIPTION       COLD TRANSIENT       STABILIZED          HOT TRANSIENT          BACKGROUND
                        ( 0-505 SEC.)      (505-1372 SEC.)      ( 0- 505 SEC.)
  FORMALDEHYDE
    PPM                      .252                .008                .011                .014
    MASS  MG                38.71                .00                 .00
  ACETALDEHYDE
    PPM                      .035                .015                .005                .002
    MASS  MG                 7.83               5.54                 .65
  ACROLEIN
    PPM                      .015                .000                .000                .000
    MASS  MG                 4.39                .00                 .00
  ACETONE
    PPM                      .048                .059                .036                .013
    MASS  MG                11.22              25.06                7.57
  PROPIONALDEHYDE
    PPM                      .010                .000                .000                .000
    MASS  MG                 3.13                .00                 .00
  CROTONALDEHYDE
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                .00                 .00
  ISOBUTYR+MEK
    PPM                      .000                .001                .000                .001
    MASS  MG                  .00                .04                 .00
  BENZALDEHYDE
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                .00                 .00
  HEXANALDEHYDE
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                .00                 .00
  METHANOL
    PPM                    36.444                .238                .173                .171
    MASS  MG              6279.27              21.59                1.45
  ETHANOL
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                .00                 .00

 3-BAG COMPOSITE RESULTS
              FORMALDEHYDE MG/MI            2.247        CROTONALD.     MG/MI            .000
              ACETALDEHYDE MG/MI            1.253        ISOBUTYR+MEK   MG/MI            .005
              ACROLEIN     MG/MI             .255        BENZALDEHYDE   MG/MI            .000
              ACETONE      MG/MI            4.622        HEXANALDEHYDE  MG/MI            .000
              PROPIONALD.  MG/MI             .182        METHANOL       MG/MI         367.478
                                                         ETHANOL        MG/MI            .000
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                     SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                            TEST CC-TT-02                      METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA               DATE  1/20/93    RUN              . FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6            DYNO  2      BAG CART  2           H .126  C .375  O .499  X .000
TRANSMISSION    5M                             ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)       TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.32 IN HG (744.7 MM HG)     DRY BULB TEMPERATURE  70.0°F ( 21.1°C)        NOX HUMIDITY C.F.   .892
RELATIVE HUMIDITY 44.2 PCT.
 BAG NUMBER                                     1                  2                   3
 BAG DESCRIPTION                         COLD TRANSIENT        STABILIZED          HOT TRANSIENT
                                        (  0-505 SEC.)      (505-1372 SEC.)      (  0- 505 SEC.)
 RUN TIME SECONDS                            505.3              867.7                507.1
 DRY/WET CORRECTION FACTOR, SAMP/BACK      .976/.989          .979/.989            .977/.989
 MEASURED DISTANCE MILES (KM)             3.57 ( 5.74)       3.82 ( 6.15)         3.57 ( 5.74)
 BLOWER FLOW RATE SCFM (SCMM)             557.5 (15.79)      557.1 (15.78)       ·556.6 (15.76)
 GAS METER FLOW RATE SCFM (SCMM)           .27 (  .01)        .27 (  .01)          .27 (  .01)
 TOTAL FLOW SCF (SCM)                     4697. ( 133.0)     8061. ( 228.3)       4706. ( 133.3)

 HC  SAMPLE METER/RANGE/PPM (BAG)         46.0/  2/ 45.97    12.1/  2/ 12.09      12.1/  2/ 12.09
 HC  BCKGRD METER/RANGE/PPM                9.4/  2/  9.39    11.0/  2/ 10.99      10.7/  2/ 10.69
 CO  SAMPLE METER/RANGE/PPM               58.1/ 12/ 56.81    13.6/ 12/ 13.06      11.8/ 12/ 11.32
 CO  BCKGRD METER/RANGE/PPM                2.9/ 12/  2.76     2.3/ 12/  2.19       2.7/ 12/  2.57
 CO2 SAMPLE METER/RANGE/PCT               77.5/ 14/ .6152    67.7/ 14/ .4680      74.7/ 14/ .5695
 CO2 BCKGRD METER/RANGE/PCT               14.4/ 14/ .0494    14.5/ 14/ .0498      14.9/ 14/ .0515
 NOX SAMPLE METER/RANGE/PPM (BAG) (D)     39.9/  1/  9.97     1.5/  1/   .38       7.8/  1/  1.96
 NOX BCKGRD METER/RANGE/PPM                2.3/  1/   .58     3.1/  1/   .78       1.0/  1/   .25
 CH4 SAMPLE PPM (1.120)                         4.10               3.90                4.77
 CH4 BCKGRD PPM                                 3.30               3.18                3.12

 DILUTION FACTOR                               18.47              24.58               20.23
 HC   CONCENTRATION PPM                        37.09               1.55                1.93
 CO   CONCENTRATION PPM                        52.38              10.63                8.56
 CO2  CONCENTRATION PCT                        .5685              .4202               .5206
 NOX  CONCENTRATION PPM                         9.42               -.37                1.72
 CH4  CONCENTRATION PPM                          .98                .85                1.80
 NMHC CONCENTRATION PPM                          .00                .59                -.04

 THC     MASS GRAMS                            8.136               .210                .163
 CO      MASS GRAMS                            8.112              2.824               1.328
 CO2     MASS GRAMS                          1384.57            1756.07             1270.27
 NOX     MASS GRAMS                            2.139               .000                .391
 CH4     MASS GRAMS                             .087               .130                .160
 NMHC    MASS GRAMS (FID)                       .000               .078                .000
 FUEL    MASS KG                               1.025              1.282                .926
 FUEL ECONOMY MPG (L/100KM)              10.45 ( 22.51)      8.96 ( 26.26)       11.56 ( 20.35)

3-BAG COMPOSITE RESULTS

                 THC     G/MI          .48                        CH4       G/MI       .035
                 CO      G/MI          .96                        NMHC      G/MI       .011
                 NOX     G/MI          .15                        CARBONYL  G/MI       .005
                                                                  ALCOHOL   G/MI       .464
                 FUEL ECONOMY MPG (L/100KM)     9.87 (23.84)      NMOG      G/MI       .479
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                 SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                           TEST CC-TT-02                          METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA              DATE  1/20/93    RUN                 - FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6           DYNO  2      BAG CART  2               H .126  C .375  O .499  X .000
TRANSMISSION    5M                            ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER           9258 MILES ( 14896 KM)     TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.32 IN HG (744.7 MM HG)      DRY BULB TEMPERATURE  70.0°F ( 21.1°C)         NOX HUMIDITY C.F.  .892
RELATIVE HUMIDITY 44.2 PCT.
  BAG NUMBER                     1                   2                    3
  BAG DESCRIPTION         COLD TRANSIENT        STABILIZED          HOT TRANSIENT        BACKGROUND
                          (  0-505 SEC.)      (505-1372 SEC.)      (  0- 505 SEC.)
  FORMALDEHYDE
    PPM                          .363                .015                 .013              .017
    MASS  MG                   56.32                 .00                  .00
  ACETALDEHYDE
    PPM                          .012                .003                 .001              .002
    MASS  MG                    2.36                 .43                  .00
  ACROLEIN
    PPM                          .000                .000                 .000              .000
    MASS  MG                     .00                 .00                  .00
  ACETONE
    PPM                          .043                .008                 .015              .005
    MASS  MG                   12.14                1.85                 3.09
  PROPIONALDEHYDE
    PPM                          .000                .000                 .000              .000
    MASS  MG                     .00                 .00                  .00
  CROTONALDEHYDE
    PPM                          .000                .000                 .000              .000
    MASS  MG                     .00                 .00                  .00
  ISOBUTYR+MEK
    PPM                          .007                .001                 .001              .001
    MASS  MG                    2.61                 .14                  .10
  BENZALDEHYDE
    PPM                          .000                .000                 .000              .000
    MASS  MG                     .00                 .00                  .00
  HEXANALDEHYDE
    PPM                          .000                .000                 .000              .000
    MASS  MG                     .00                 .00                  .00
  METHANOL
    PPM                        46.346                .274                 .209              .284
    MASS  MG                 7975.38                 .00                  .00
  ETHANOL
    PPM                          .000                .000                 .000              .000
    MASS  MG                     .00                 .00                  .00

 3-BAG COMPOSITE RESULTS
            FORMALDEHYDE MG/MI              3.276          CROTONALD.     MG/MI           .000
            ACETALDEHYDE MG/MI               .196          ISOBUTYR+MEK   MG/MI           .179
            ACROLEIN     MG/MI               .000          BENZALDEHYDE   MG/MI           .000
            ACETONE      MG/MI              1.194          HEXANALDEHYDE  MG/MI           .000
            PROPIONALD.  MG/MI               .000          METHANOL       MG/MI        463.908
                                                           ETHANOL        MG/MI           .000
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FAX COVER LETTER

DATE: 02/19/93

PLEASE DELIVER TO: Mr. Jesse Jones

FAX NUMBER: 806-742-3540

FROM: Kevin Whitney, Phone: 210-522-5869 SwRI CHARGE NO. 08#

Southwest Research Institute
Department of Emissions Research
Automotive Products and Emissions Research Division
Fax Number (512) 522-3950

WE ARE TRANSMITTING 5 PAGES (including this cover page)

If transmission is not complete, please call (512) 522-2609

MESSAGE:

Dear Jesse:

Sorry it took me a while to get around to this. Here are copies of the emissions data from the two tests you ran. After going over the data, I feel the low NOx number in bag 2 on the test CC-TT-02 is valid. The NOx level was probably low enough that instrumentation variability caused the background bag to read higher than the sample bag. This especially makes sense when you look at the data from the previous test (CC-TT-01). NOx was very low in bag 2 on that test, also. If you have any questions, feel free to call me at 210-522-5869.

Sincerely,

Kevin A. Whitney
Engineer
Department of Emissions Research

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                    SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                          TEST CC-TT-02                        METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA             DATE  1/20/93    RUN                 FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6          DYNO  2     BAG CART  2              H .126  C .375  O .499  X .000
TRANSMISSION    5M                           ACTUAL ROAD LOAD  5.74 KW ( 7.70 HP)
ODOMETER         14896 KM (  9258 MILES)     TEST WEIGHT  1587 KG ( 3500 LBS)

BAROMETER 744.7 MM HG ( 29.32 IN HG)    DRY BULB TEMPERATURE  21.1'C ( 70.0'F)     NOX HUMIDITY C.F.  .892
RELATIVE HUMIDITY 44.2 PCT.
 BAG NUMBER                                   1                   2                   3
 BAG DESCRIPTION                       COLD TRANSIENT        STABILIZED         HOT TRANSIENT
                                       ( 0-505 SEC.)      (505-1372 SEC.)      (  0- 505 SEC.)
 RUN TIME SECONDS                          505.3               867.7              507.1
 DRY/WET CORRECTION FACTOR, SAMP/BACK    .976/.989          .979/.989          .977/.989
 MEASURED DISTANCE KM (MILES)           5.74 ( 3.57)       6.15 ( 3.82)       5.74 ( 3.57)
 BLOWER FLOW RATE SCMM (SCFM)          15.79 ( 557.5)     15.78 ( 557.1)     15.76 ( 556.6)
 GAS METER FLOW RATE SCMM (SCFM)         .01 (   .27)       .01 (   .27)       .01 (   .27)
 TOTAL FLOW SCM (SCF)                  133.0 (  4697.)    228.3 (  8061.)    133.3 (  4706.)

 HC  SAMPLE METER/RANGE/PPM (BAG)      46.0/  2/ 45.97    12.1/  2/ 12.09    12.1/  2/ 12.09
 HC  BCKGRD METER/RANGE/PPM             9.4/  2/  9.39    11.0/  2/ 10.99    10.7/  2/ 10.69
 CO  SAMPLE METER/RANGE/PPM            58.1/ 12/ 56.81    13.6/ 12/ 13.06    11.8/ 12/ 11.32
 CO  BCKGRD METER/RANGE/PPM             2.9/ 12/  2.76     2.3/ 12/  2.19     2.7/ 12/  2.57
 CO2 SAMPLE METER/RANGE/PCT            77.5/ 14/ .6152    67.7/ 14/ .4680    74.7/ 14/ .5695
 CO2 BCKGRD METER/RANGE/PCT            14.4/ 14/ .0494    14.5/ 14/ .0498    14.9/ 14/ .0515
 NOX SAMPLE METER/RANGE/PPM (BAG) (D)  39.9/  1/  9.97     1.5/  1/   .38     7.8/  1/  1.96
 NOX BCKGRD METER/RANGE/PPM             2.3/  1/   .58     3.1/  1/   .78     1.0/  1/   .25
 CH4 SAMPLE PPM (1.120)                        4.10               3.90               4.77
 CH4 BCKGRD PPM                                3.30               3.18               3.12

 DILUTION FACTOR                              18.47              24.58              20.23
 HC   CONCENTRATION PPM                       37.09               1.55               1.93
 CO   CONCENTRATION PPM                       52.38              10.63               8.56
 CO2  CONCENTRATION PCT                       .5685              .4202              .5206
 NOX  CONCENTRATION PPM                        9.42               -.37               1.72
 CH4  CONCENTRATION PPM                         .98                .85               1.80
 NMHC CONCENTRATION PPM                         .00                .59               -.04

 THC     MASS GRAMS                           8.136               .210               .163
 CO      MASS GRAMS                           8.112              2.824              1.328
 CO2     MASS GRAMS                         1384.57            1756.07            1270.27
 NOX     MASS GRAMS                           2.139               .000               .391
 CH4     MASS GRAMS                            .087               .130               .160
 NMHC    MASS GRAMS (FID)                      .000               .078               .000
 FUEL    MASS KG                              1.025              1.282               .926
 FUEL ECONOMY L/100KM (MPG)            22.51 ( 10.45)     26.26 (  8.96)     20.35 ( 11.56)

 3-BAG COMPOSITE RESULTS

            THC    G/MI                 .48      CH4      G/MI        .03
            CO     G/MI                 .96      NMHC     G/MI        .01
            NOX    G/MI                 .15      CARBONYL G/MI        .00
                                                          ALCOHOL  G/MI        .46
  FUEL ECONOMY MPG (L/100KM)        9.87 (23.84)          NMOG     G/MI       .479
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                     SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
   COMPUTER PROGRAM LDT 1.0-R          3-BAG CARB FTP VEHICLE EMISSION RESULTS         PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                         TEST CC-TT-02                            METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA            DATE  1/20/93    RUN                     FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6         DYNO  2      BAG CART  2                 H .126  C .375  O .499  X .000
TRANSMISSION    5M                          ACTUAL ROAD LOAD  5.74 KW ( 7.70 HP)
ODOMETER         14896 KM (  9258 MILES)    TEST WEIGHT  1587 KG ( 3500 LBS)

BAROMETER 744.7 MM HG ( 29.32 IN HG)     DRY BULB TEMPERATURE  21.1'C ( 70.0'F)       NOX HUMIDITY C.F.  .892
RELATIVE HUMIDITY 44.2 PCT.
 BAG NUMBER               1                2                3
 BAG DESCRIPTION      COLD TRANSIENT     STABILIZED      HOT TRANSIENT        BACKGROUND
                      (  0-505 SEC.)   (505-1372 SEC.)  (  0- 505 SEC.)
 FORMALDEHYDE
   PPM                     .363             .015             .013                .017
   MASS  MG               56.32             .00              .00
 ACETALDEHYDE
   PPM                     .012             .003             .001                .002
   MASS  MG                2.36             .43              .00
 ACROLEIN
   PPM                     .000             .000             .000                .000
   MASS  MG                .00              .00              .00
 ACETONE
   PPM                     .043             .008             .015                .005
   MASS  MG               12.14            1.85             3.09
 PROPIONALDEHYDE
   PPM                     .000             .000             .000                .000
   MASS  MG                .00              .00              .00
 CROTONALDEHYDE
   PPM                     .000             .000             .000                .000
   MASS  MG                .00              .00              .00
 ISOBUTYR+MEK
   PPM                     .007             .001             .001                .001
   MASS  MG                2.61             .14              .10
 BENZALDEHYDE
   PPM                     .000             .000             .000                .000
   MASS  MG                .00              .00              .00
 HEXANALDEHYDE
   PPM                     .000             .000             .000                .000
   MASS  MG                .00              .00              .00
 METHANOL
   PPM                   46.346             .274             .209                .284
   MASS  MG             7975.38             .00              .00
 ETHANOL
   PPM                     .000             .000             .000                .000
   MASS  MG                .00              .00              .00

3-BAG COMPOSITE RESULTS
  FORMALDEHYDE MG/KM (MG/MI)             2.036 (  3.276)       CROTONALD.    MG/KM (MG/MI)            .000 (    .
  ACETALDEHYDE MG/KM (MG/MI)              .122 (   .196)       ISOBUTYR+MEK  MG/KM (MG/MI)            .111 (    .
  ACROLEIN     MG/KM (MG/MI)              .000 (   .000)       BENZALDEHYDE  MG/KM (MG/MI)            .000 (    .
  ACETONE      MG/KM (MG/MI)              .742 (  1.194)       HEXANALDEHYDE MG/KM (MG/MI)            .000 (    .
  PROPIONALD.  MG/KM (MG/MI)              .000 (   .000)       METHANOL      MG/KM (MG/MI)         288.321 (463.
                                                               ETHANOL       MG/KM (MG/MI)            .000 (    .
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                    SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
   COMPUTER PROGRAM LDT 1.0-R         3-BAG CARB FTP VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                        TEST CC-TT-01                         METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA           DATE  1/19/93    RUN                  FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6        DYNO  2      BAG CART  2              H .126  C .375  O .499  X .000
TRANSMISSION    5M                         ACTUAL ROAD LOAD  5.74 KW ( 7.70 HP)
ODOMETER         14896 KM (  9258 MILES)   TEST WEIGHT  1587 KG ( 3500 LBS)

BAROMETER 744.2 MM HG ( 29.30 IN HG)    DRY BULB TEMPERATURE  22.2°C ( 72.0°F)      NOX HUMIDITY C.F.   .880
RELATIVE HUMIDITY 38.6 PCT.
  BAG NUMBER                                    1                   2                   3
  BAG DESCRIPTION                        COLD TRANSIENT        STABILIZED         HOT TRANSIENT
                                         ( 0-505 SEC.)      (505-1372 SEC.)     ( 0- 505 SEC.)
  RUN TIME SECONDS                           505.2               867.0               505.4
  DRY/WET CORRECTION FACTOR, SAMP/BACK     .977/.989           .980/.989           .978/.989
  MEASURED DISTANCE KM (MILES)            5.76 ( 3.58)        6.16 ( 3.83)        5.74 ( 3.57)
  BLOWER FLOW RATE SCMM (SCFM)           15.78 ( 557.2)      15.77 ( 556.9)      15.76 ( 556.5)
  GAS METER FLOW RATE SCMM (SCFM)          .01 (   .27)        .01 (   .27)        .01 (   .27)
  TOTAL FLOW SCM (SCF)                   132.9 (  4694.)     228.0 (  8051.)     132.8 (  4689.)

  HC  SAMPLE METER/RANGE/PPM (BAG)       37.8/  2/ 37.78     11.9/  2/ 11.89     11.5/  2/ [illegible]
  HC  BCKGRD METER/RANGE/PPM              7.6/  2/  7.60      9.9/  2/  9.89      9.7/  2/  9.69
  CO  SAMPLE METER/RANGE/PPM             33.6/ 12/ 32.60     17.1/ 12/ 16.47     10.6/ 12/ 10.16
  CO  BCKGRD METER/RANGE/PPM              1.1/ 12/  1.04      1.4/ 12/  1.33      1.3/ 12/  1.23
  CO2 SAMPLE METER/RANGE/PCT             77.8/ 14/ .6203     67.4/ 14/ .4640     74.1/ 14/ .5601
  CO2 BCKGRD METER/RANGE/PCT             14.0/ 14/ .0478     13.7/ 14/ .0466     13.8/ 14/ .0470
  NOX SAMPLE METER/RANGE/PPM (BAG) (D)   45.8/  1/ 11.43      2.7/  1/   .68     27.0/  1/  6.77
  NOX BCKGRD METER/RANGE/PPM              1.5/  1/   .38      1.9/  1/   .48      1.1/  1/   .28
  CH4 SAMPLE PPM (1.120)                         4.29                3.55                4.39
  CH4 BCKGRD PPM                                 2.54                2.52                2.51

  DILUTION FACTOR                               18.42               24.78               20.57
  HC   CONCENTRATION PPM                        30.59                2.40                2.27
  CO   CONCENTRATION PPM                        30.61               14.77                8.70
  CO2  CONCENTRATION PCT                        .5751               .4193               .5154
  NOX  CONCENTRATION PPM                        11.07                 .22                6.51
  CH4  CONCENTRATION PPM                         1.88                1.13                2.00
  NMHC CONCENTRATION PPM                          .13                1.07                 .02

  THC      MASS GRAMS                           6.521                .365                .189
  CO       MASS GRAMS                           4.737               3.920               1.345
  CO2      MASS GRAMS                         1399.64             1750.06             1253.19
  NOX      MASS GRAMS                           2.478                .085               1.454
  CH4      MASS GRAMS                            .167                .172                .178
  NMHC     MASS GRAMS (FID)                      .010                .141                .001
  FUEL     MASS KG                              1.031               1.279                .914
  FUEL ECONOMY L/100KM (MPG)              22.55 ( 10.43)      26.18 (  8.98)      20.08 ( 11.71)

 3-BAG COMPOSITE RESULTS

            THC    G/MI              .40      CH4      G/MI        .05
            CO     G/MI              .91      NMHC     G/MI        .02
            NOX    G/MI              .27      CARBONYL G/MI        .01
                                                        ALCOHOL  G/MI       .37
  FUEL ECONOMY MPG (L/100KM)      9.91 (23.73)          NMOG     G/MI       .396
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                        SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
   COMPUTER PROGRAM LOT 1.0-R         3-BAG CARB FTP VEHICLE EMISSION RESULTS         PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                         TEST CC-TT-01                     METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA            DATE  1/19/93    RUN              FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6         DYNO  2      BAG CART  2          H .126  C .375  O .499  X .000
TRANSMISSION    5M                          ACTUAL ROAD LOAD  5.74 KW ( 7.70 HP)
ODOMETER         14896 KM (  9258 MILES)    TEST WEIGHT  1587 KG ( 3500 LBS)

BAROMETER 744.2 MM HG ( 29.30 IN HG)     DRY BULB TEMPERATURE  22.2°C ( 72.0°F)         NOX HUMIDITY C.F.  .880
RELATIVE HUMIDITY 38.6 PCT.
  BAG NUMBER                 1                  2                  3
  BAG DESCRIPTION      COLD TRANSIENT       STABILIZED       HOT TRANSIENT        BACKGROUND
                       (  0-505 SEC.)     (505-1372 SEC.)    (  0- 505 SEC.)
  FORMALDEHYDE
    PPM                     .252               .008               .011               .014
    MASS  MG               38.71               .00                .00
  ACETALDEHYDE
    PPM                     .035               .015               .005               .002
    MASS  MG                7.83              5.54                .65
  ACROLEIN
    PPM                     .015               .000               .000               .000
    MASS  MG                4.39               .00                .00
  ACETONE
    PPM                     .048               .059               .036               .013
    MASS  MG               11.22             25.06               7.57
  PROPIONALDEHYDE
    PPM                     .010               .000               .000               .000
    MASS  MG                3.13               .00                .00
  CROTONALDEHYDE
    PPM                     .000               .000               .000               .000
    MASS  MG                .00                .00                .00
  ISOBUTYR+MEK
    PPM                     .000               .001               .000               .001
    MASS  MG                .00                .04                .00
  BENZALDEHYDE
    PPM                     .000               .000               .000               .000
    MASS  MG                .00                .00                .00
  HEXANALDEHYDE
    PPM                     .000               .000               .000               .000
    MASS  MG                .00                .00                .00
  METHANOL
    PPM                   36.444               .238               .173               .171
    MASS  MG             6279.27              21.59               1.45
  ETHANOL
    PPM                     .000               .000               .000               .000
    MASS  MG                .00                .00                .00

 3-BAG COMPOSITE RESULTS
   FORMALDEHYDE MG/KM (MG/MI)          1.396 (  2.247)      CROTONALD.     MG/KM (MG/MI)              .000 (    .0
   ACETALDEHYDE MG/KM (MG/MI)           .779 (  1.253)      ISOBUTYR+MEK   MG/KM (MG/MI)              .003 (    .0
   ACROLEIN     MG/KM (MG/MI)           .158 (   .255)      BENZALDEHYDE   MG/KM (MG/MI)              .000 (    .0
   ACETONE      MG/KM (MG/MI)          2.872 (  4.622)      HEXANALDEHYDE  MG/KM (MG/MI)              .000 (    .0
   PROPIONALD.  MG/KM (MG/MI)           .113 (   .182)      METHANOL       MG/KM (MG/MI)           228.389 (367.4
                                                            ETHANOL        MG/KM (MG/MI)              .000 (    .0
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SOUTHWEST RESEARCH INSTITUTE

[illegible] CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO TEXAS USA 78228-0510 • (210) 684-5111 • TELEX 244846

FAX COVER LETTER

DATE: March 31, 1995

PLEASE DELIVER TO: Jesse Jones

COMPANY / FIRM: Texas Tech

FAX NUMBER: 806-742-3540

FROM: Kevin Whitney **SWRI CHARGE NO.** ______

Southwest Research Institute
Department of Emissions Research
Automotive Products and Emissions Research Division

FAX NUMBER (210) 522-3950

WE ARE TRANSMITTING ______ **PAGES (including this cover page)**
If transmission is not complete, please call (210) 522-2609

MESSAGE:

To: Jesse Jones
Texas Tech
806-742-3563 voice
806-742-3540 FAX

From: Kevin Whitney
Southwest Research Institute
210-522-5869 voice

FLAME IONIZ DET

ONE HALF HAD EA

Jesse,

Attached are 6 pages of test data from your Corsica. The data has been processed according to CARB methodology, so there are no OMHCE numbers. The NMOG numbers are calculated using the FID results for the gasoline portion of the exhaust. The initial tests in January 93 are CC-TT-01 and CC-TT-02. The test after mileage is TECH12/94. On the 12/94 test we had extreme difficulty on the cold start. The vehicle had to be cranked about 15 seconds, and it ran rough while in open-loop.

The data from the 12/94 test shows higher emissions for all exhaust components over all 3 bags of the FTP. In addition, fuel economy is only slightly lower on this test than previous tests. I suspect this is an indication of a failed catalyst.

Please feel free to call me at the voice number listed above if you have further questions.

Sincerely,

KEVIN.

Kevin Whitney

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                     SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
   COMPUTER PROGRAM LDT 1.2-R        3-BAG CARB FTP  VEHICLE EMISSION RESULTS       PROJECT NO. 08-6761-004

VEHICLE NUMBER  577                        TEST TECH12/94                          METHANOL  M85      AS RECEIV
VEHICLE MODEL   88 CHEVY CORSICA           DATE 12/16/94     RUN                   FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6        DYNO  2      BAG CART  2                H .126  C .375  O .499  X .000
TRANSMISSION    M5                         ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER         30983 MILES ( 49851 KM)   TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.32 IN HG (744.7 MM HG)     DRY BULB TEMPERATURE  68.0'F ( 20.0'C)        NOX HUMIDITY C.F. 1.048
RELATIVE HUMIDITY 80.7 PCT.
  BAG NUMBER                                      1                  2                  3
  BAG DESCRIPTION                          COLD TRANSIENT       STABILIZED         HOT TRANSIENT
                                           (  0-505 SEC.)    (505-1372 SEC.)     (  0- 505 SEC.)
  RUN TIME SECONDS                             505.5              867.2               505.7
  DRY/WET CORRECTION FACTOR, SAMP/BACK       .968/.981          .972/.981          .970/.981
  MEASURED DISTANCE MILES (KM)               3.61 ( 5.80)       3.84 ( 6.18)       3.58 ( 5.77)
  BLOWER FLOW RATE SCFM (SCMM)              565.4 (16.01)      567.2 (16.06)      562.9 (15.94)
  GAS METER FLOW RATE SCFM (SCMM)             .27 (  .01)        .28 (  .01)        .28 (  .01)
  TOTAL FLOW SCF (SCM)                      4766. ( 135.0)     8202. ( 232.3)     4747. ( 134.4)

  HC  SAMPLE METER/RANGE/PPM (BAG)        82.5/   2/  82.45   10.9/  ·2/  10.89   14.5/   2/  14.49
  HC  BCKGRD METER/RANGE/PPM               5.7/   2/   5.70    5.3/   2/   5.30    4.7/   2/   4.70
  CO  SAMPLE METER/RANGE/PPM              88.0/  13/ 214.97   37.6/  12/  36.74   43.6/  13/  99.87
  CO  BCKGRD METER/RANGE/PPM                .2/  13/    .44     .2/  12/    .20     .2/  13/    .44
  CO2 SAMPLE METER/RANGE/PCT              80.2/  14/  .6589   66.4/  14/  .4456   72.8/  14/  .5354
  CO2 BCKGRD METER/RANGE/PCT              12.1/  14/  .0387   11.9/  14/  .0380   12.3/  14/  .0395
  NOX SAMPLE METER/RANGE/PPM (BAG) (D)    53.2/   1/  13.22   12.9/   1/   3.29   56.0/   1/  13.91
  NOX BCKGRD METER/RANGE/PPM                .6/   1/    .16     .5/   1/    .13     .0/   1/    .00
  CH4 SAMPLE PPM (1.160)                         8.90               7.20              10.22
  CH4 BCKGRD PPM                                 2.27               2.34               2.45

  DILUTION FACTOR                                16.78              25.69              21.17
  HC   CONCENTRATION PPM                         77.10               5.80              10.02
  CO   CONCENTRATION PPM                        204.71              35.11              95.25
  CO2  CONCENTRATION PCT                         .6225              .4090              .4978
  NOX  CONCENTRATION PPM                         13.07               3.16              13.91
  CH4  CONCENTRATION PPM                          6.77               4.95               7.88
  NMHC CONCENTRATION PPM                         -3.33                .06                .55

  THC     MASS GRAMS                            17.296               .777               .830
  CO      MASS GRAMS                            32.166              9.494             14.906
  CO2     MASS GRAMS                           1538.14            1739.54            1225.11
  NOX     MASS GRAMS                             3.535              1.471              3.746
  CH4     MASS GRAMS                              .609               .766               .706
  NMHC    MASS GRAMS (FID)                        .000               .008               .043
  FUEL    MASS KG                                1.174              1.278               .910
  FUEL ECONOMY MPG (L/100KM)                9.23 ( 25.50)      9.02 ( 26.08)     11.83 ( 19.89)

 3-BAG COMPOSITE  RESULTS

                 THC    G.MI          1.167                     CH4       G/MI         .193
                 CO     G/MI          4.280                     NMHC      G/MI         .004
                 NOX    G/MI           .690                     CARBONYL  G/MI         .022
                                                                ALCOHOL   G/MI         .948
                 FUEL ECONOMY MPG (L/100KM)    9.73 (24.18)    NMOG      G/MI         .975  (RAF=1.00)
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                    SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.2-R        3-BAG CARB FTP  VEHICLE EMISSION RESULTS        PROJECT NO. 08-6761-004

VEHICLE NUMBER  577                            TEST TECH12/94                          METHANOL  M85      AS RECEIV
VEHICLE MODEL   88 CHEVY CORSICA               DATE 12/16/94    RUN                    FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6            DYNO  2       BAG CART  2               H .126  C .375  O .499  X .000
TRANSMISSION    M5                             ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER         30983 MILES ( 49851 KM)       TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.32 IN HG (744.7 MM HG)      DRY BULB TEMPERATURE  68.0°F ( 20.0°C)        NOX HUMIDITY C.F. 1.048
RELATIVE HUMIDITY 80.7 PCT.
  BAG NUMBER                   1                   2                   3
  BAG DESCRIPTION        COLD TRANSIENT       STABILIZED          HOT TRANSIENT        BACKGROUND
                         ( 0-505 SEC.)      (505-1372 SEC.)      (  0- 505 SEC.)
  FORMALDEHYDE
    PPM                     2.127                .012                .012                .009
    MASS  MG               345.48                 .76                 .52
  ACETALDEHYDE
    PPM                      .051                .001                .000                .001
    MASS  MG                11.87                 .00                 .00
  ACROLEIN
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                 .00                 .00
  ACETONE
    PPM                      .020                .005                .026                .007
    MASS  MG                 4.32                 .00                5.95
  PROPIONALDEHYDE
    PPM                      .012                .002                .004                .002
    MASS  MG                 3.10                 .00                 .49
  CROTONALDEHYDE
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                 .00                 .00
  ISOBUTYR+MEK
    PPM                      .022                .006                .010                .005
    MASS  MG                 6.88                 .68                1.97
  BENZALDEHYDE
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                 .00                 .00
  HEXANALDEHYDE
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                 .00                 .00
  METHANOL
    PPM                    93.944                .199                .612                .201
    MASS  MG             16315.29                1.35               72.64
  ETHANOL
    PPM                      .000                .000                .000                .000
    MASS  MG                  .00                 .00                 .00

 3-BAG COMPOSITE  RESULTS
             FORMALDEHYDE MG/MI          20.094         CROTONALD.    MG/MI            .000
             ACETALDEHYDE MG/MI            .686         ISOBUTYR+MEK  MG/MI            .641
             ACROLEIN     MG/MI            .000         BENZALDEHYDE  MG/MI            .000
             ACETONE      MG/MI            .707         HEXANALDEHYDE MG/MI            .000
             PROPIONALD.  MG/MI            .216         METHANOL      MG/MI         947.966
                                                        ETHANOL       MG/MI            .000
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                    SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP  VEHICLE EMISSION RESULTS        PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                           TEST CC-TT-02                        METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA              DATE  1/20/93     RUN              - FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6           DYNO  2      BAG CART  2             H .126  C .375  O .499  X .000
TRANSMISSION    5M                            ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)      TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.32 IN HG (744.7 MM HG)     DRY BULB TEMPERATURE  70.0°F ( 21.1°C)        NOX HUMIDITY C.F.  .892
RELATIVE HUMIDITY 44.2 PCT.
  BAG NUMBER                                       1                  2                   3
  BAG DESCRIPTION                            COLD TRANSIENT       STABILIZED          HOT TRANSIENT
                                             ( 0-505 SEC.)     (505-1372 SEC.)      ( 0- 505 SEC.)
  RUN TIME SECONDS                               505.3              867.7               507.1
  DRY/WET CORRECTION FACTOR, SAMP/BACK         .976/.989          .979/.989           .977/.989
  MEASURED DISTANCE MILES (KM)               3.57 ( 5.74)       3.82 ( 6.15)        3.57 ( 5.74)
  BLOWER FLOW RATE SCFM (SCMM)               557.5 (15.79)      557.1 (15.78)       556.6 (15.76)
  GAS METER FLOW RATE SCFM (SCMM)             .27 (  .01)        .27 (  .01)         .27 (  .01)
  TOTAL FLOW SCF (SCM)                       4697. ( 133.0)     8061. ( 228.3)      4706. ( 133.3)

  HC  SAMPLE METER/RANGE/PPM (BAG)         46.0/  2/  45.97   12.1/  2/  12.09   12.1/  2/  12.09
  HC  BCKGRD METER/RANGE/PPM                9.4/  2/   9.39   11.0/  2/  10.99   10.7/  2/  10.69
  CO  SAMPLE METER/RANGE/PPM               58.1/ 12/  56.81   13.6/ 12/  13.06   11.8/ 12/  11.32
  CO  BCKGRD METER/RANGE/PPM                2.9/ 12/   2.76    2.3/ 12/   2.19    2.7/ 12/   2.57
  CO2 SAMPLE METER/RANGE/PCT               77.5/ 14/  .6152   67.7/ 14/  .4680   74.7/ 14/  .5695
  CO2 BCKGRD METER/RANGE/PCT               14.4/ 14/  .0494   14.5/ 14/  .0498   14.9/ 14/  .0515
  NOX SAMPLE METER/RANGE/PPM (BAG) (D)     39.9/  1/   9.97    1.5/  1/    .38    7.8/  1/   1.96
  NOX BCKGRD METER/RANGE/PPM                2.3/  1/    .58    3.1/  1/    .78    1.0/  1/    .25
  CH4 SAMPLE PPM (1.120)                          4.10               3.90               4.77
  CH4 BCKGRD PPM                                  3.30               3.18               3.12

  DILUTION FACTOR                                 18.47              24.58              20.23
  HC   CONCENTRATION PPM                          37.09               1.55               1.93
  CO   CONCENTRATION PPM                          52.38              10.63               8.56
  CO2  CONCENTRATION PCT                          .5685              .4202              .5206
  NOX  CONCENTRATION PPM                           9.42               -.37               1.72
  CH4  CONCENTRATION PPM                            .98                .85               1.80
  NMHC CONCENTRATION PPM                            .00                .59               -.04

  THC     MASS GRAMS                              8.136               .210               .163
  CO      MASS GRAMS                              8.112              2.824              1.328
  CO2     MASS GRAMS                            1384.57            1756.07            1270.27
  NOX     MASS GRAMS                              2.139               .000               .391
  CH4     MASS GRAMS                               .087               .130               .160
  NMHC    MASS GRAMS (FID)                         .000               .078               .000
  FUEL    MASS KG                                 1.025              1.282               .926
  FUEL ECONOMY MPG (L/100KM)                 10.45 ( 22.51)     8.96 ( 26.26)      11.56 ( 20.35)

 3-BAG COMPOSITE  RESULTS

                 THC    G/MI          .51                      CH4       G/MI        .035
                 CO     G/MI          .96                      NMHC      G/MI        .011
                 NOX    G/MI          .15                      CARBONYL  G/MI        .005
                                                               ALCOHOL   G/MI        .464
                 FUEL ECONOMY MPG (L/100KM)    9.87 (23.84)    NMOG      G/MI        .479
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                         SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP  VEHICLE EMISSION RESULTS       PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                        TEST CC-TT-02                           METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA           DATE  1/20/93    RUN                  - FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6        DYNO  2       BAG CART  2               H .126  C .375  O .499  X .000
TRANSMISSION    5M                         ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)   TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.32 IN HG (744.7 MM HG)     DRY BULB TEMPERATURE  70.0°F ( 21.1°C)        NOX HUMIDITY C.F.  .892
RELATIVE HUMIDITY 44.2 PCT.
 BAG NUMBER                  1                  2                   3
 BAG DESCRIPTION       COLD TRANSIENT       STABILIZED        HOT TRANSIENT         BACKGROUND
                       (  0-505 SEC.)     (505-1372 SEC.)     (  0- 505 SEC.)
 FORMALDEHYDE
   PPM                      .363              .015                .013                 .017
   MASS  MG                56.32              .00                 .00
 ACETALDEHYDE
   PPM                      .012              .003                .001                 .002
   MASS  MG                 2.36              .43                 .00
 ACROLEIN
   PPM                      .000              .000                .000                 .000
   MASS  MG                 .00               .00                 .00
 ACETONE
   PPM                      .043              .008                .015                 .005
   MASS  MG                12.14              1.85                3.09
 PROPIONALDEHYDE
   PPM                      .000              .000                .000                 .000
   MASS  MG                 .00               .00                 .00
 CROTONALDEHYDE
   PPM                      .000              .000                .000                 .000
   MASS  MG                 .00               .00                 .00
 ISOBUTYR+MEK
   PPM                      .007              .001                .001                 .001
   MASS  MG                 2.61              .14                 .10
 BENZALDEHYDE
   PPM                      .000              .000                .000                 .000
   MASS  MG                 .00               .00                 .00
 HEXANALDEHYDE
   PPM                      .000              .000                .000                 .000
   MASS  MG                 .00               .00                 .00
 METHANOL
   PPM                    46.346              .274                .209                 .284
   MASS  MG             7975.38               .00                 .00
 ETHANOL
   PPM                      .000              .000                .000                 .000
   MASS  MG                 .00               .00                 .00

 3-BAG COMPOSITE  RESULTS
            FORMALDEHYDE MG/MI            3.276         CROTONALD.     MG/MI             .000
            ACETALDEHYDE MG/MI             .196         ISOBUTYR+MEK   MG/MI             .179
            ACROLEIN     MG/MI             .000         BENZALDEHYDE   MG/MI             .000
            ACETONE      MG/MI            1.194         HEXANALDEHYDE  MG/MI             .000
            PROPIONALD.  MG/MI             .000         METHANOL       MG/MI          463.908
                                                        ETHANOL        MG/MI             .000
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                 SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R        3-BAG CARB FTP  VEHICLE EMISSION RESULTS       PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                    TEST CC-TT-01                          METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA       DATE  1/19/93    RUN                 · FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6    DYNO  2       BAG CART  2              H .126  C .375  O .499  X .000
TRANSMISSION    5M                     ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)   TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.30 IN HG (744.2 MM HG)    DRY BULB TEMPERATURE  72.0°F ( 22.2°C)       NOX HUMIDITY C.F.  .880
RELATIVE HUMIDITY 38.6 PCT.
  BAG NUMBER                                  1                  2                  3
  BAG DESCRIPTION                       COLD TRANSIENT       STABILIZED        HOT TRANSIENT
                                       ( 0-505 SEC.)     (505-1372 SEC.)    ( 0- 505 SEC.)
  RUN TIME SECONDS                        505.2               867.0              505.4
  DRY/WET CORRECTION FACTOR, SAMP/BACK   .977/.989           .980/.989          .978/.989
  MEASURED DISTANCE MILES (KM)          3.58 ( 5.76)        3.83 ( 6.16)       3.57 ( 5.74)
  BLOWER FLOW RATE SCFM (SCMM)         557.2 (15.78)       556.9 (15.77)      556.5 (15.76)
  GAS METER FLOW RATE SCFM (SCMM)        .27 (  .01)         .27 (  .01)        .27 (  .01)
  TOTAL FLOW SCF (SCM)                 4694. ( 132.9)      8051. ( 228.0)     4689. ( 132.8)

  HC  SAMPLE METER/RANGE/PPM (BAG)    37.8/  2/  37.78    11.9/  2/  11.89    11.5/  2/  11.49
  HC  BCKGRD METER/RANGE/PPM           7.6/  2/   7.60     9.9/  2/   9.89     9.7/  2/   9.69
  CO  SAMPLE METER/RANGE/PPM          33.6/ 12/  32.60    17.1/ 12/  16.47    10.6/ 12/  10.16
  CO  BCKGRD METER/RANGE/PPM           1.1/ 12/   1.04     1.4/ 12/   1.33     1.3/ 12/   1.23
  CO2 SAMPLE METER/RANGE/PCT          77.8/ 14/  .6203    67.4/ 14/  .4640    74.1/ 14/  .5601
  CO2 BCKGRD METER/RANGE/PCT          14.0/ 14/  .0478    13.7/ 14/  .0466    13.8/ 14/  .0470
  NOX SAMPLE METER/RANGE/PPM (BAG) (D) 45.8/  1/  11.43    2.7/  1/    .68    27.0/  1/   6.77
  NOX BCKGRD METER/RANGE/PPM           1.5/  1/    .38     1.9/  1/    .48     1.1/  1/    .28
  CH4 SAMPLE PPM (1.120)                    4.29               3.55               4.39
  CH4 BCKGRD PPM                            2.54               2.52               2.51

  DILUTION FACTOR                           18.42              24.78              20.57
  HC   CONCENTRATION PPM                    30.59               2.40               2.27
  CO   CONCENTRATION PPM                    30.61              14.77               8.70
  CO2  CONCENTRATION PCT                    .5751              .4193              .5154
  NOX  CONCENTRATION PPM                    11.07                .22               6.51
  CH4  CONCENTRATION PPM                     1.88               1.13               2.00
  NMHC CONCENTRATION PPM                      .13               1.07                .02

  THC     MASS GRAMS                       6.521               .365               .189
  CO      MASS GRAMS                       4.737              3.920              1.345
  CO2     MASS GRAMS                     1399.64            1750.06            1253.19
  NOX     MASS GRAMS                       2.478               .085              1.454
  CH4     MASS GRAMS                        .167               .172               .178
  NMHC    MASS GRAMS (FID)                  .010               .141               .001
  FUEL    MASS KG                          1.031              1.279               .914
  FUEL ECONOMY MPG (L/100KM)          10.43 ( 22.55)      8.98 ( 26.18)     11.71 ( 20.08)

 3-BAG COMPOSITE  RESULTS

                   THC    G/MI         .44                    CH4       G/MI        .047
                   CO     G/MI         .91                    NMHC      G/MI        .020
                   NOX    G/MI         .27                    CARBONYL  G/MI        .009
                                                              ALCOHOL   G/MI        .367
                   FUEL ECONOMY MPG (L/100KM)    9.91 (23.73)     NMOG      G/MI        .396
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                          SOUTHWEST RESEARCH INSTITUTE - DEPARMENT OF EMISSIONS RESEARCH
  COMPUTER PROGRAM LDT 1.0-R       3-BAG CARB FTP  VEHICLE EMISSION RESULTS       PROJECT NO. 08-4527-008

VEHICLE NUMBER  577                       TEST CC-TT-01                          METHANOL  EM-1399-F
VEHICLE MODEL   88 CHEVY CORSICA          DATE  1/19/93    RUN                   FUEL DENSITY  6.620 LB/GAL
ENGINE          2.8 L (171 CID)-V-6       DYNO  2      BAG CART  2               H .126  C .375  O .499  X .000
TRANSMISSION    5M                        ACTUAL ROAD LOAD  7.70 HP ( 5.74 KW)
ODOMETER          9258 MILES ( 14896 KM)  TEST WEIGHT  3500 LBS ( 1587 KG)

BAROMETER  29.30 IN HG (744.2 MM HG)    DRY BULB TEMPERATURE  72.0'F ( 22.2'C)        NOX HUMIDITY C.F.  .880
RELATIVE HUMIDITY 38.6 PCT.
 BAG NUMBER                1                  2                  3
 BAG DESCRIPTION       COLD TRANSIENT      STABILIZED        HOT TRANSIENT        BACKGROUND
                       (  0-505 SEC.)    (505-1372 SEC.)    (  0- 505 SEC.)
 FORMALDEHYDE
   PPM                     .252               .008               .011               .014
   MASS  MG               38.71               .00                .00
 ACETALDEHYDE
   PPM                     .035               .015               .005               .002
   MASS  MG                7.83               5.54               .65
 ACROLEIN
   PPM                     .015               .000               .000               .000
   MASS  MG                4.39               .00                .00
 ACETONE
   PPM                     .048               .059               .036               .013
   MASS  MG               11.22              25.06               7.57
 PROPIONALDEHYDE
   PPM                     .010               .000               .000               .000
   MASS  MG                3.13               .00                .00
 CROTONALDEHYDE
   PPM                     .000               .000               .000               .000
   MASS  MG                .00                .00                .00
 ISOBUTYR+MEK
   PPM                     .000               .001               .000               .001
   MASS  MG                .00                .04                .00
 BENZALDEHYDE
   PPM                     .000               .000               .000               .000
   MASS  MG                .00                .00                .00
 HEXANALDEHYDE
   PPM                     .000               .000               .000               .000
   MASS  MG                .00                .00                .00
 METHANOL
   PPM                    36.444              .238               .173               .171
   MASS  MG             6279.27              21.59               1.45
 ETHANOL
   PPM                     .000               .000               .000               .000
   MASS  MG                .00                .00                .00

 3-BAG COMPOSITE  RESULTS
                FORMALDEHYDE MG/MI           2.247        CROTONALD.     MG/MI           .000
                ACETALDEHYDE MG/MI           1.253        ISOBUTYR+MEK   MG/MI           .005
                ACROLEIN     MG/MI            .255        BENZALDEHYDE   MG/MI           .000
                ACETONE      MG/MI           4.622        HEXANALDEHYDE  MG/MI           .000
                PROPIONALD.  MG/MI            .182        METHANOL       MG/MI        367.478
                                                          ETHANOL        MG/MI           .000
```

APPENDIX D

Initial Oil Cnsumption Test Results from Southwest Research Institute

S O U T H W E S T   R E S E A R C H   I N S T I T U T E

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (512) 684-5111 • TELEX 244846

ENGINE, FUEL, AND VEHICLE RESEARCH DIVISION
TELECOPIER: 512/522-2019

July 7, 1992

Dr. Tim Maxwell
Department of Mechanical Engineering
Texas Tech University
Lubbock, Texas 79409
Fax. 806-742-3540

Subject: Southwest Research Institute Preproposal No. EVR-1126,
"Oil Consumption Measurement for A Methanol Vehicle Under Emission Cycle"

Dear Dr. Maxwell:

We are pleased to submit the above preproposal. The following is the content of the proposed tasks.

OBJECTIVE

The objective of this proposal is to measure oil consumption of a methanol vehicle on chassis dynamometer under EPA Federal Test Procedure.

APPROACH

The approach is to use the on-line oil consumption measurement system developed by SwRI using SO_2 tracer method. I have enclosed two SAE papers and one brochure for your reference. This literature describes the capability of the on-line oil consumption measurement system. Currently, the system uses relatively long exhaust gas sampling line as described in the literature and it is not appropriate for the FTP transient cycle test. However, another system is being setup in the one of SwRI engine test cell. This new system will be able to measure true real-time oil consumption; therefore, it is appropriate for the proposed project and planned for the proposed project.

Briefly, the engine will be operated on relatively high sulfur oil (~1%wt). This oil has good sulfur balance over a certain distilled fraction and it will be available for the proposed project. Since the fuel is methanal, there is no provision necessary for the fuel preparation in terms of sulfur content. By knowing fuel and air flow rate, the oil consumption in grams per unit time can be calculated by measuring SO_2 concentration in the exhaust gas since sulfur concentration in the oil is known. SwRI has developed a PC data acquisition system for the on-line oil consumption measurement. The oil consumption will be continuously monitored and stored for the data analysis.

PROJECT TASK

Pretest Preparation

The oil consumption measurement system will be relocated to the vehicle emissions test laboratory of Department of Emissions Research at SwRI and prepared for the measurement. The engine will have to be run on no sulfur oil for a while in order to eliminate sulfur background. This test will usually last about 4 to 8 hours. Then, the oil is replaced with the qualified high sulfur oil, and the preliminary test will be conducted for making sure all the instrumentation functions. As soon as the measurement results are determined to be acceptable, the vehicle test under the FTP transient cycle will be initiated as follows.

Test 1

The oil consumption under the FTP transient cycle will be measured before the vehicle is tested for the long term road test. The oil consumption measurement results will be analyzed and plotted against the test time.

Test 2

The oil consumption under the FTP transient cycle will be measured after the vehicle test is completed. The oil consumption measurement results will be analyzed and plotted against the test time.

REPORTING

A comprehensive final report will be prepared and submitted to Texas Tech University at the completion of the project.

COST AND TIME ESTIMATE

The cost plus fixed fee contract cost estimate is $41,000. The estimate project duration is two (2) months. Upon receiving your acceptance, SwRI will prepare a formal proposal and submit it to Texas Tech University with contractual documentation.

CLOSURE

Engine tribological problems associated with Alcohol engines still exist. The result of this project is expected to provide an additional information useful for investigating such problems. It is particular interest to observe how much of the effect of component dimensional change due to the wear on the oil consumption will affect the emissions characteristics under transient conditions. SwRI is very interested in participating to the program and hoping to provide Texas Tech University the valuable results.

If you have any questions, please feel free to call me at 512-522-3194. Our facsimile number of 512-522-2019 for your convenience.

Sincerely,

Susumu Ariga

Susumu Ariga
Acting Manager
Engine Tribology Section
Department of Engine Research

Approved:

R.H. Thring

for Shannon Vinyard, Director
Department of Engine Research

/sjh

SOUTHWEST RESEARCH INSTITUTE

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ENGINE, FUEL, AND VEHICLE RESEARCH DIVISION
TELECOPIER (210) 522-2019

April 23, 1993

Dr. Tim Maxwell
Professor
Department of Mechanical Engineering
Texas Tech Research
Lubbock, Texas 79409
Fax: 806-742-3540

Subject: Progress Report No. 1 for Southwest Research Institute Project 03-5461, "Oil Consumption Measurement for A Methanol Vehicle Under Emission Cycle"

Dear Dr. Maxwell:

This is the first progress report for the subject project. The work has been completed for the first oil consumption meaurement as Test 1, and the car has been picked up by a student from Texas Tech Research. The following describes the work accomplishment, problems, and future plans.

OBJECTIVE

The objective of this project is to measure oil consumption of a methanol vehicle on a chassis dynamometer under EPA Federal Test Procedures before and after the vehicle durability tests.

WORK ACCOMPLISHMENTS

The oil consumption measurement system was refined to increase the sampling response time by means of electronic sample gas pressure closed loop control in order to increase the accuracy of the measurement under transient operating conditions. The device was designed, fabricated, and tested by actually conducting the oil consumption measurement on one engine installed at SwRI. After the acceptable gas sampling response time (less than one second) was determined, the oil consumption measurement system hardware and a PC data acquisition system were relocated from the engine research laboratory to the vehicle emissions test laboratory and prepared for the measurement.

In order to prepare for the oil consumption testing, the methanol powered vehicle (GM Corsica 2.8 liter V6 engine) was instrumented for flow rates of intake air and fuel and engine pertinent temperatures and pressures. A laminar flow element (LFE) with pressure transducers was used for the intake air flow measurement in real-time, and a micro-motion real-time mass fuel flow meter was used for fuel flow measurement. An exhaust gas sampling probe was fitted to the exhaust pipe close to the manifold flange. The original oil was drained, saved, and a zero sulfur synthetic oil was installed. The vehicle was then driven at normal operating temperatures to mix the zero sulfur oil with any residue of the original oil. This process was repeated through three changes of zero sulfur oil to insure that any sulfur residue from the original oil had been flushed from the system.

The vehicle was installed on the dynamometer and tested to establish baseline performance of the oil consumption instrumentation with zero sulfur oil in the vehicle. The zero sulfur oil was then drained, and replaced for the balance of the testing with an oil of known sulfur concentration that has proven to be very stable in maintaining this fixed concentration throughout the testing cycle.

The test preparation went smoothly. The EPA Urban Dynamometer Driving Test cycle was performed on the vehicle from cold start condition, followed by a repeat of the cycle from hot start condition. The total length of the test is approximately 60 minutes, including soaking time, and the actual vechicle operating time is 40 minutes. In addition, the vehicle was operated under three steady-state conditions to obtain additional oil consumption information from this particular vehicle. The results are descussed below.

After the completion of the first test, the vehicle was returned to Texas Tech on April 12, 1993.

PROBLEMS

The oil consumption measurement system had a problem dealing with the SO_2 detection instrumentation. The problem was found when the system was being used for another SwRI project. The correction could be made; however, it took about one month to complete the investigation and applying the solution. The problem was that the NO_X signal interfered with the SO_2 signal. Therefore, the measured SO_2 concetration was actually higher than the true value. This incident delayed the test schedule by about one month.

DISCUSSION OF TEST 1 RESULTS

The EPA Urban Dynamometer Driving Test cycle was performed on the vehicle from cold start condition, followed by a repeat of the cycle from hot start condition. Figures 1 and 2 represent plots of real-time oil consumption and vehicle speed during these two test cycles. Note that Figure 1, the cold start cycle, shows considerably less oil consumption during the first 800 seconds of the cycle when compared to the hot start cycle of Figure 2. Figures 3 through 9 illustrate these same two test cycles plotted together, but with an expanded time base to allow a more detailed comparison. While changes in vehicle speed during these test cycles is the primary cause of variations in oil consumption, engine temperature seems to be another major contributor. Figures 10 and 11 show coolant temperature out of the block, plotted with oil consumption. Note that the low oil consumption during the first 800 seconds of the cold start test, Figure 10, shows lower temperatures during the same time period.

Following the cycling tests, three additional tests were performed at steady-state conditions. These were 2675 RPM in fourth gear, 1500 RPM in fifth gear, and idle at 900 RPM. Results of these tests are presented in Figures 12 through 14. It is quite apparent in these figures that engine temperature, as monitored by coolant temperature, has a very marked effect on the oil consumption. These data suggest that total engine oil consumption could be significantly reduced by a moderate reduction in coolant temperature perhaps to as low as 180°F. It will be extremely important when the vehicle has accumulated the required road miles and is returned to have these tests repeated, that the engine temperatures are duplicated very closely so that any variations in oil consumption reflect only effects of the accumulated miles.

FUTURE PLANS

Test 2 will commence after the vehicle durability test is completed. The vechile durability test will be conducted by Texas Tech Research.

If you have any questions, please feel free to call me at 210-522-3956. Our facsimile number of 512-522-2019 for your convenience.

Sincerely,

Jim Barbee
Engineering Technologist
Department of Engine Research

Approved:

Susumu Ariga, Acting Manager
Engine Tribology
Department of Engine Research

ckh

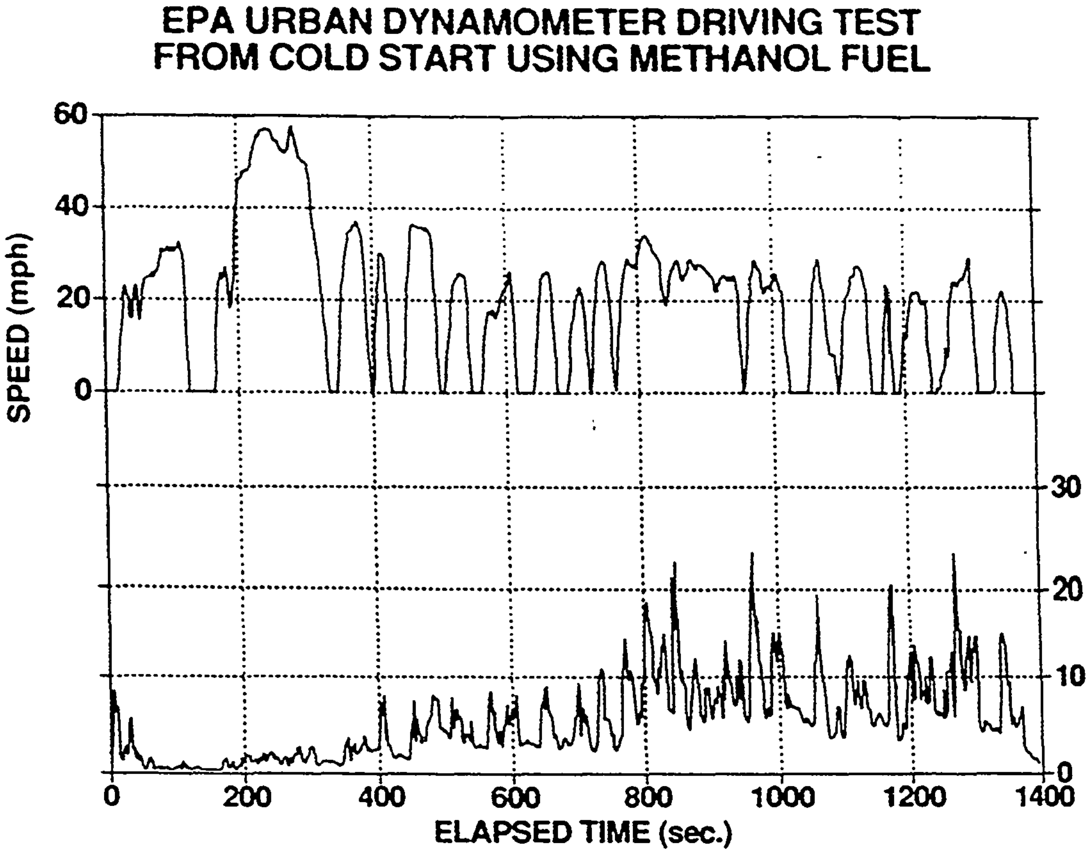


FIGURE 1

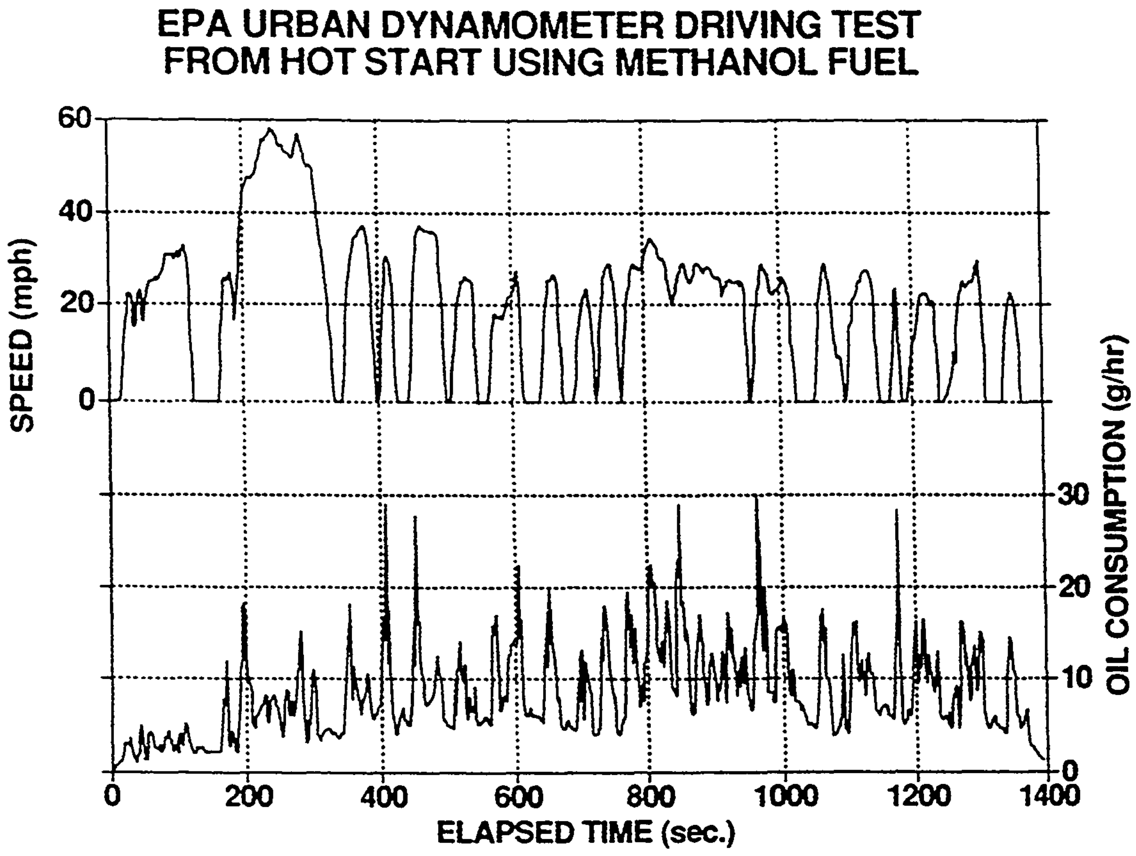


FIGURE 2

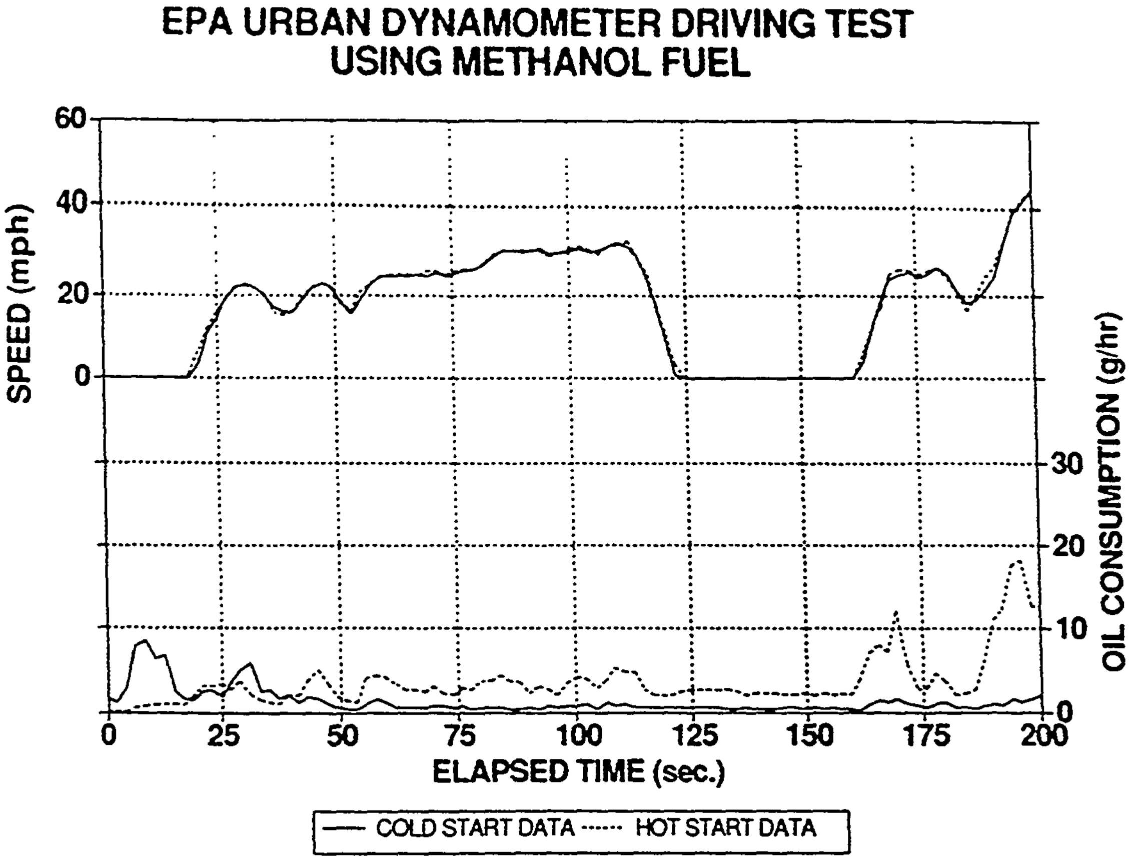

EPA URBAN DYNAMOMETER DRIVING TEST
USING METHANOL FUEL

FIGURE 3

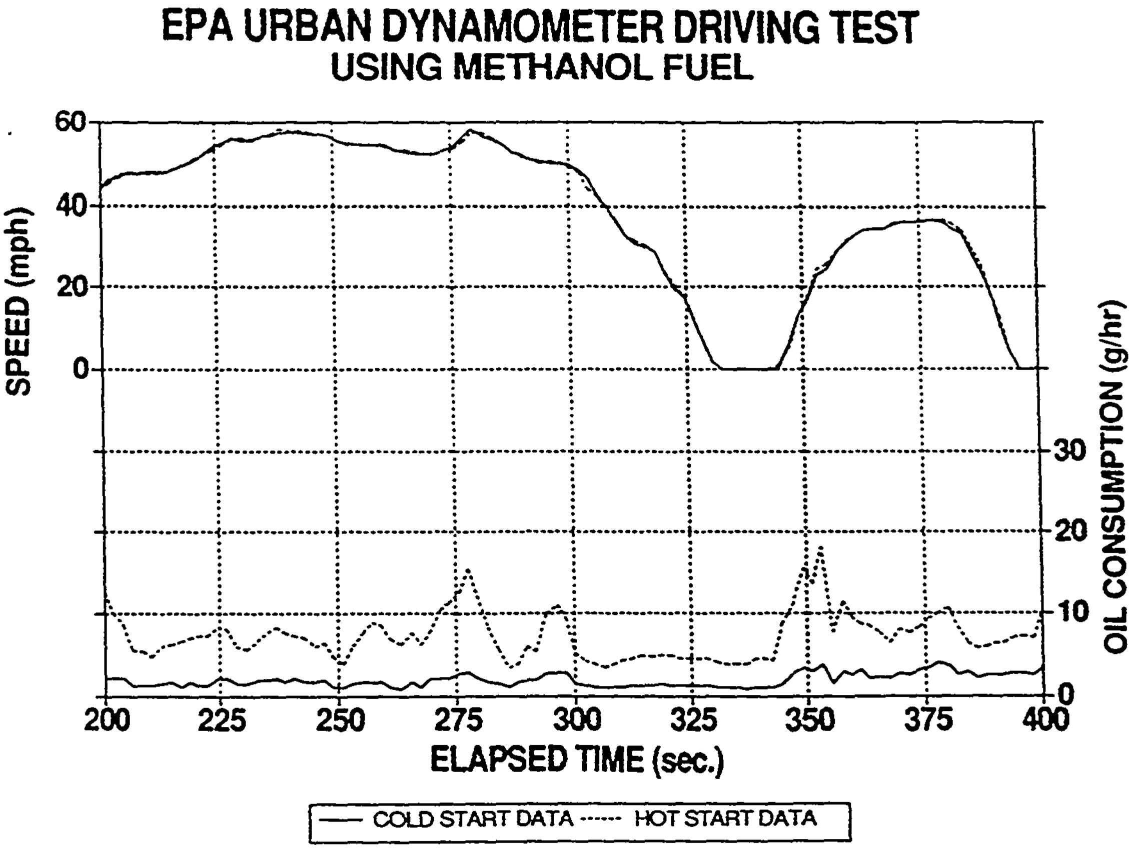

EPA URBAN DYNAMOMETER DRIVING TEST
USING METHANOL FUEL

FIGURE 4

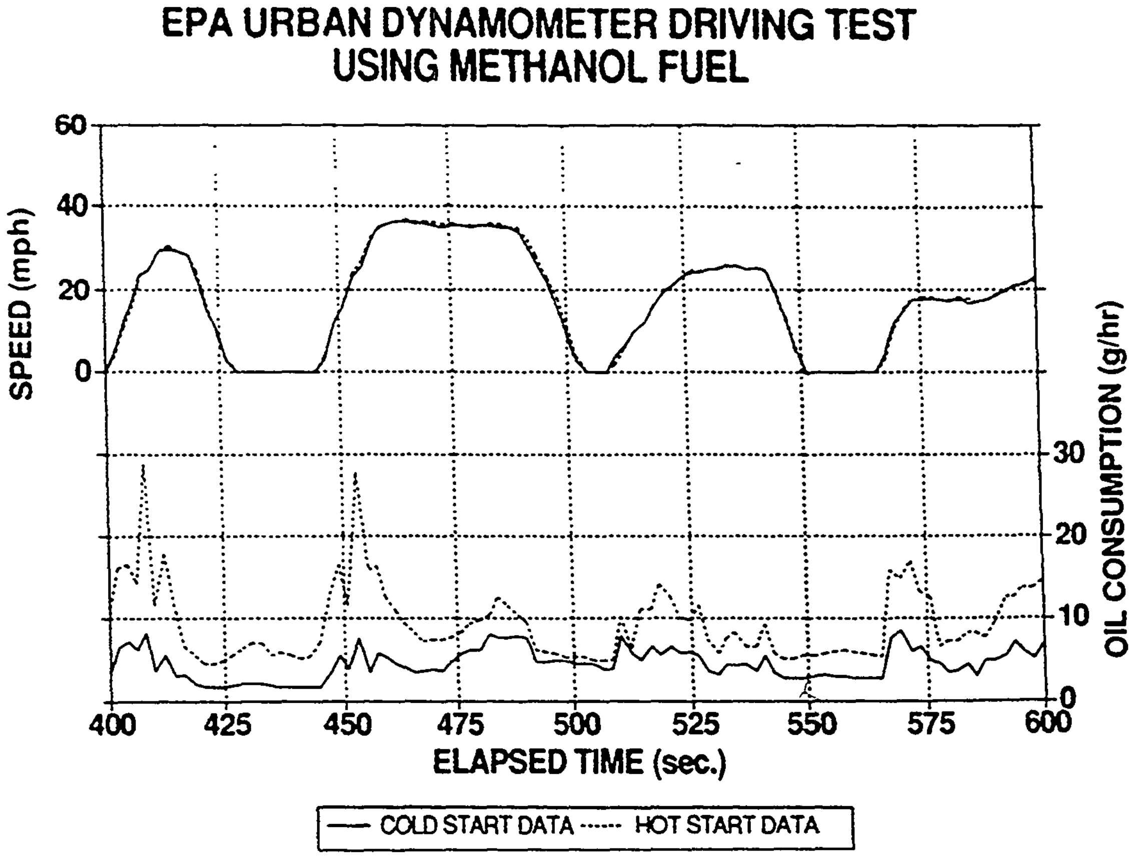


FIGURE 5

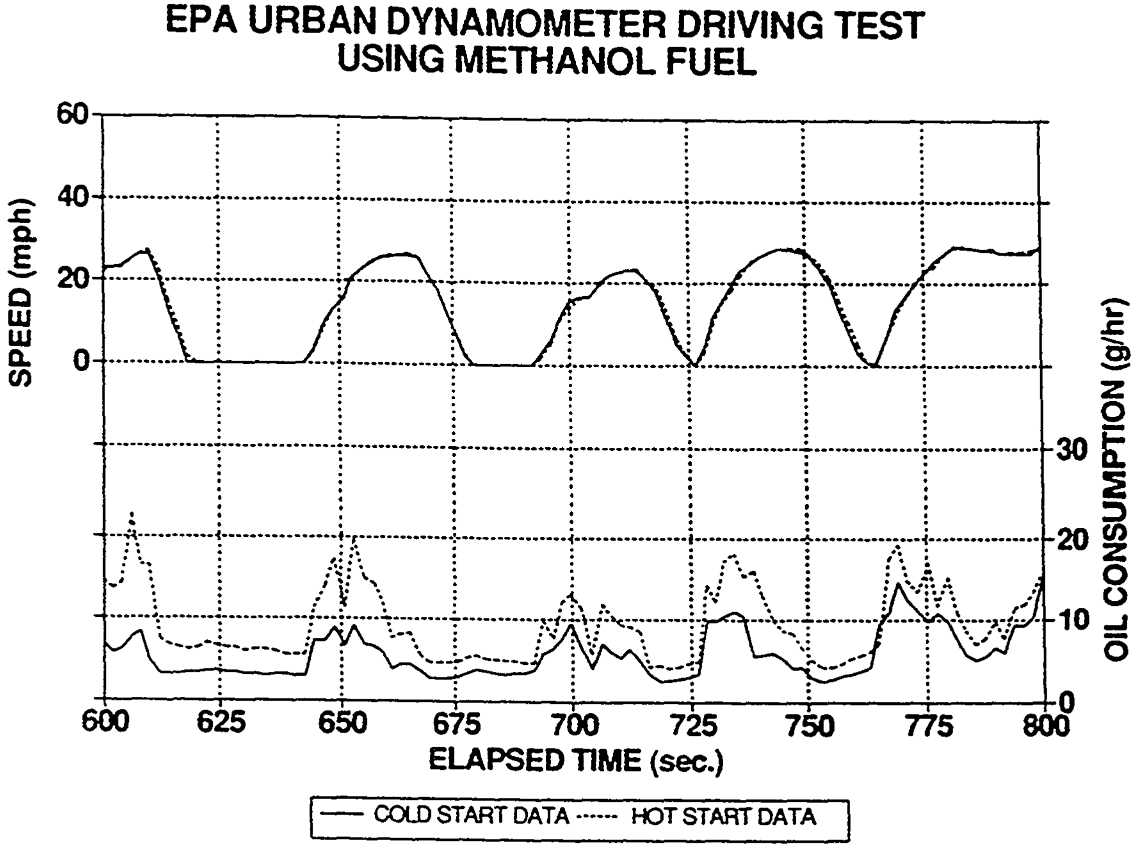


FIGURE 6

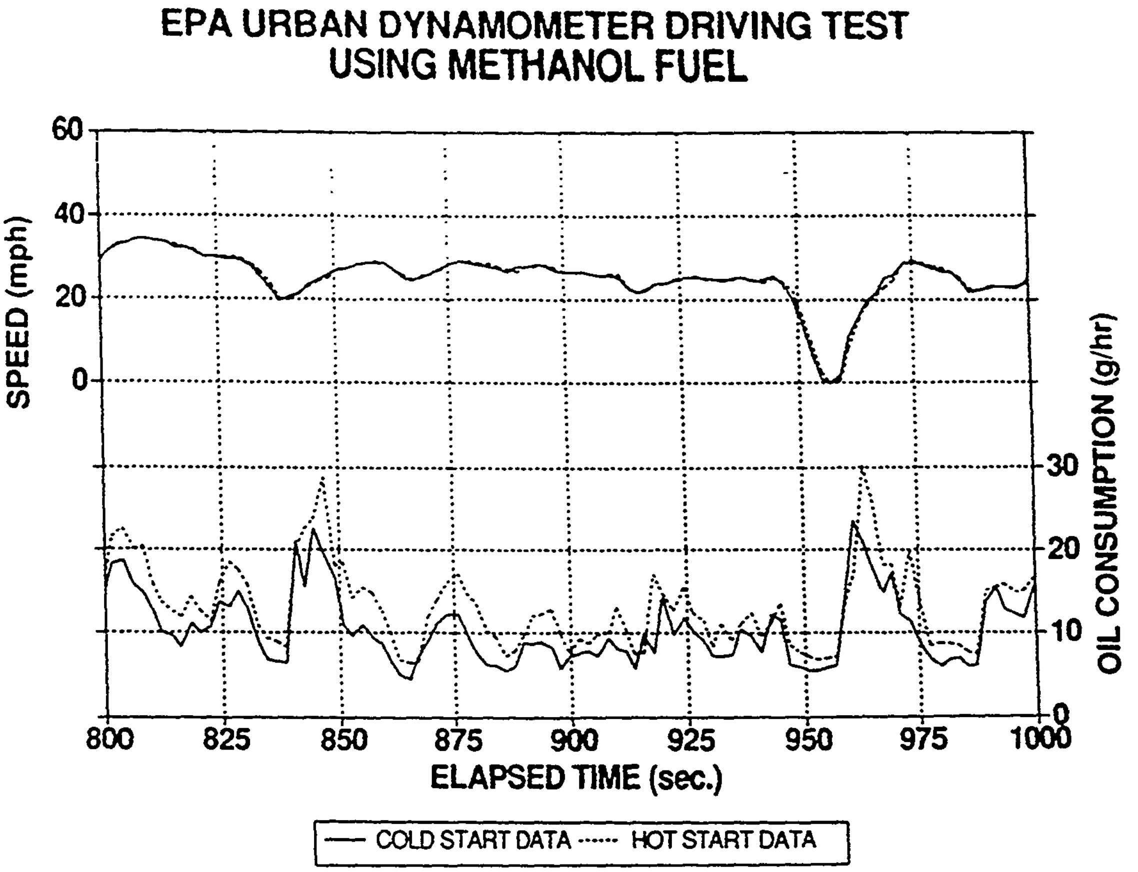


FIGURE 7

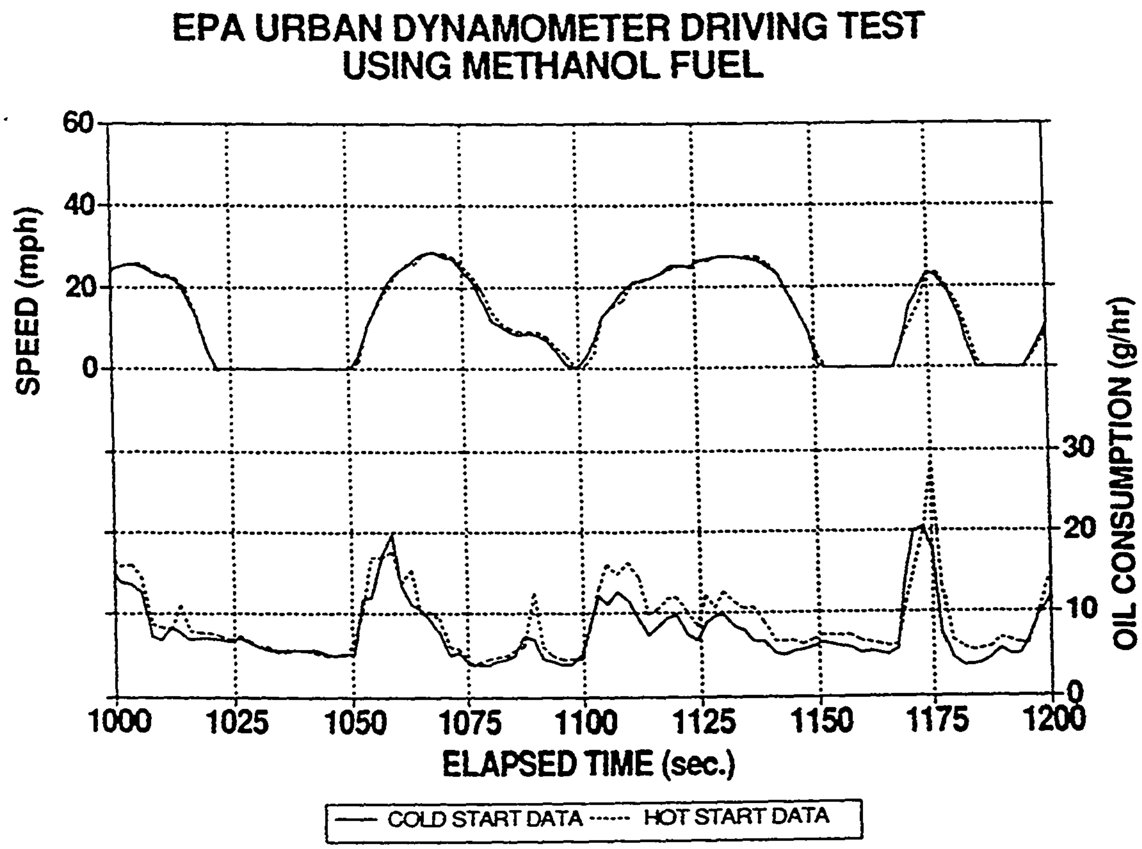


FIGURE 8

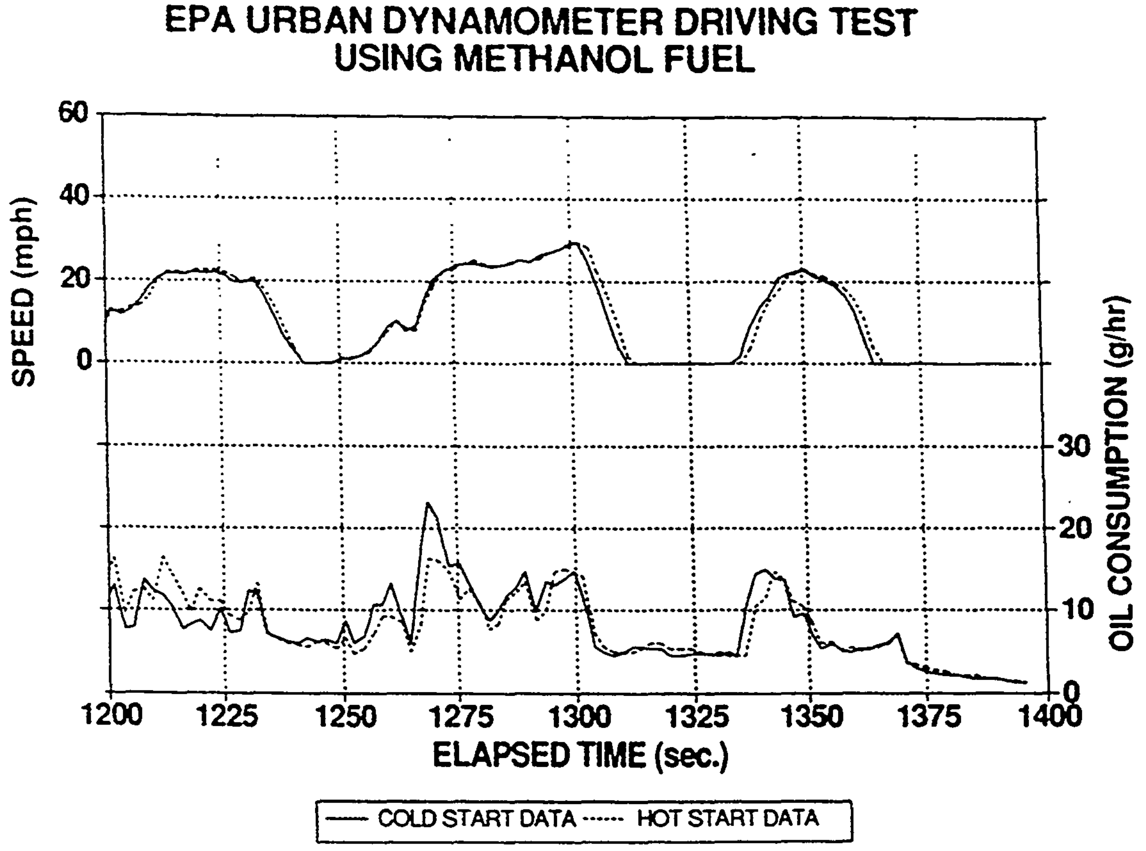


FIGURE 9

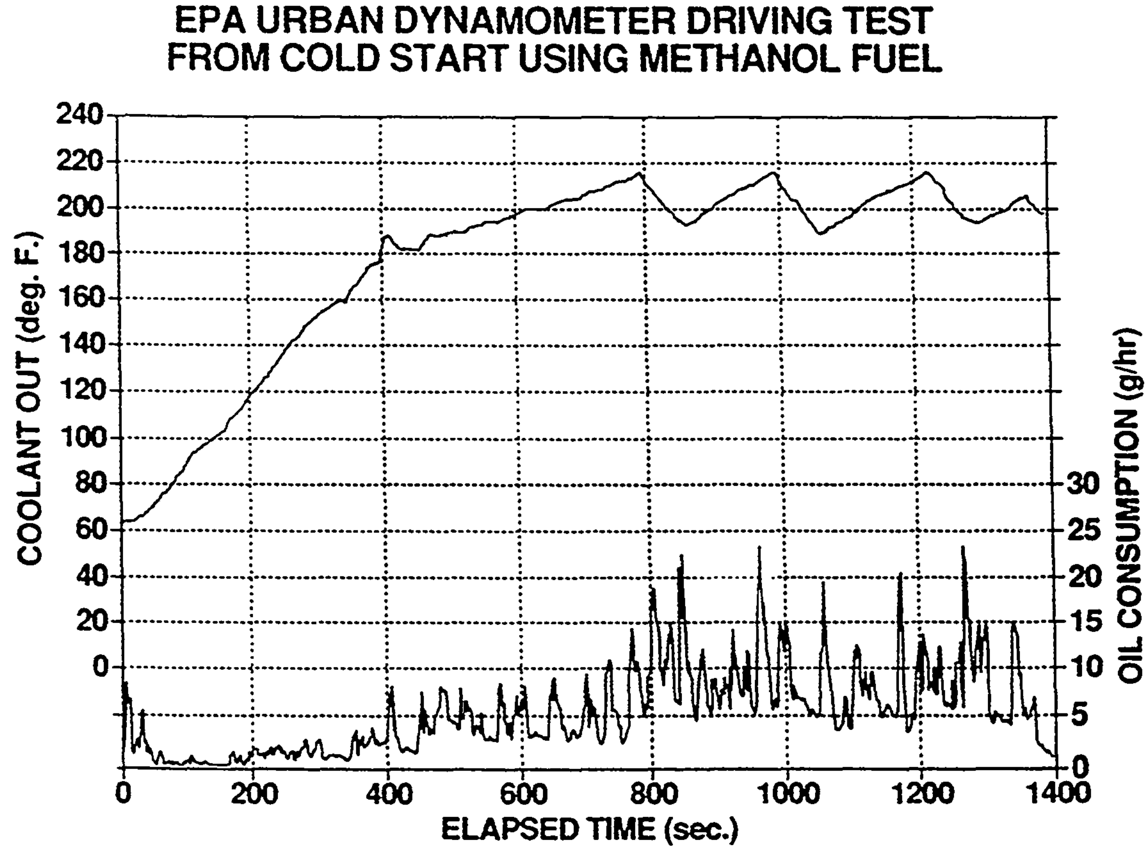
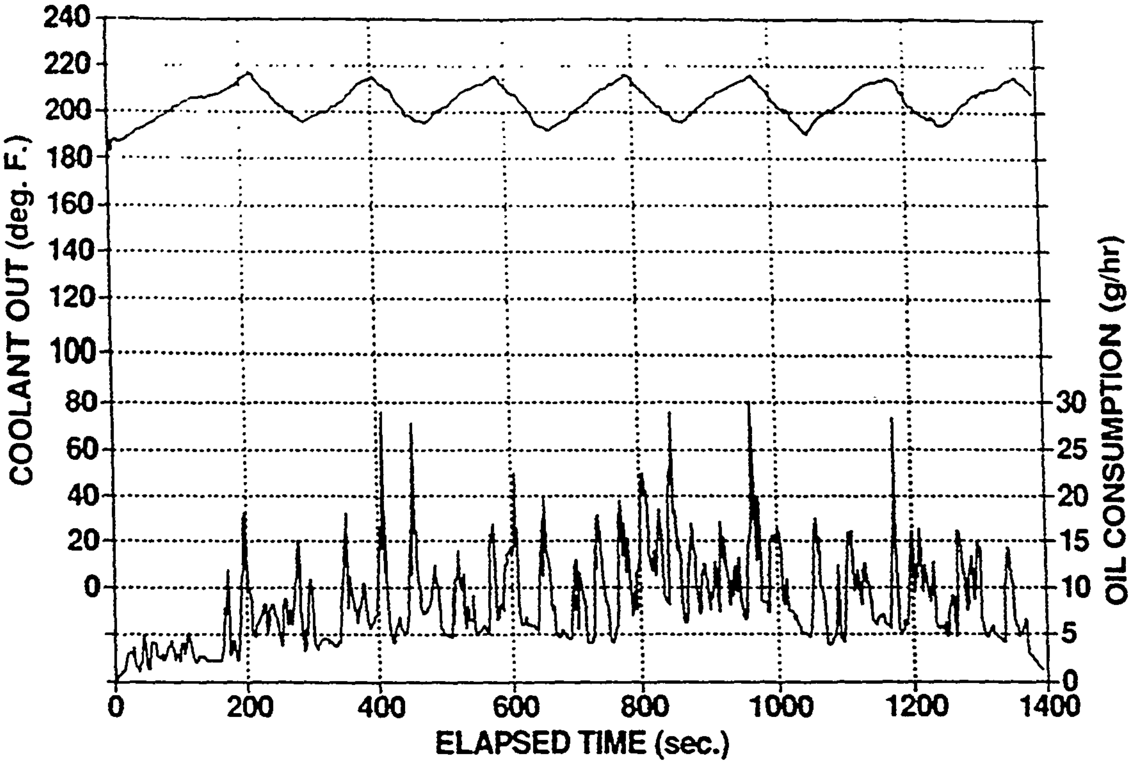
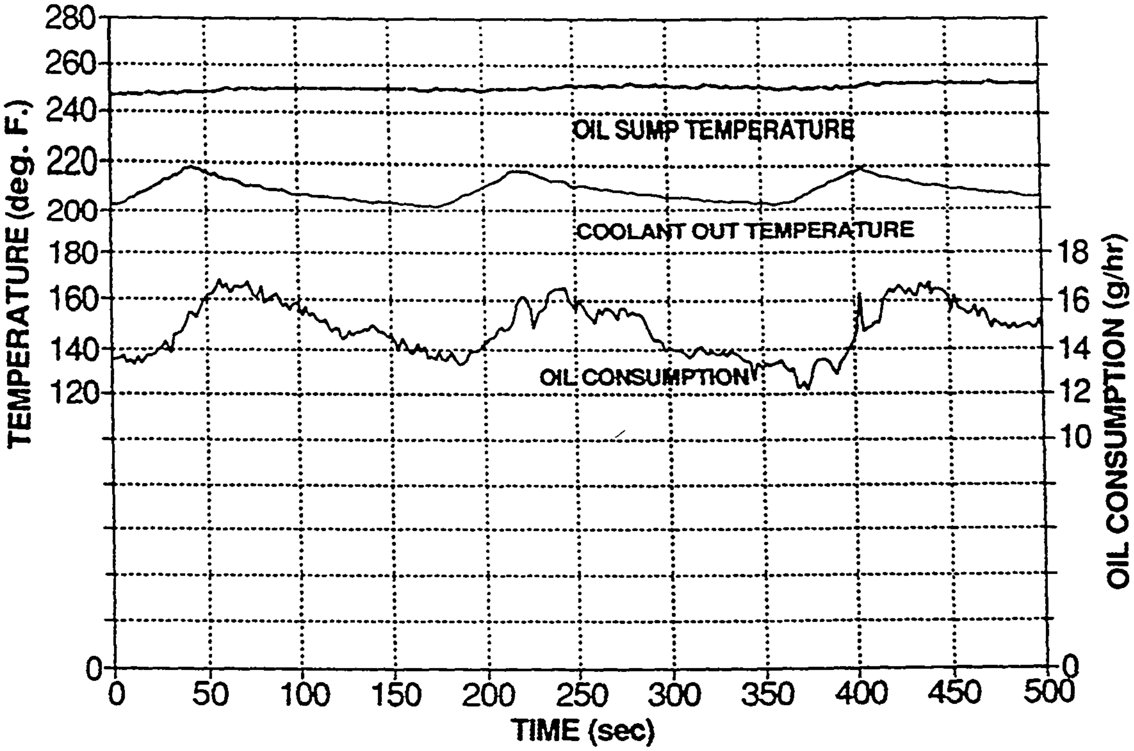


FIGURE 10



EPA URBAN DYNAMOMETER DRIVING TEST FROM HOT START USING METHANOL FUEL

FIGURE 11



2675 RPM STEADY STATE CONDITION

FIGURE 12

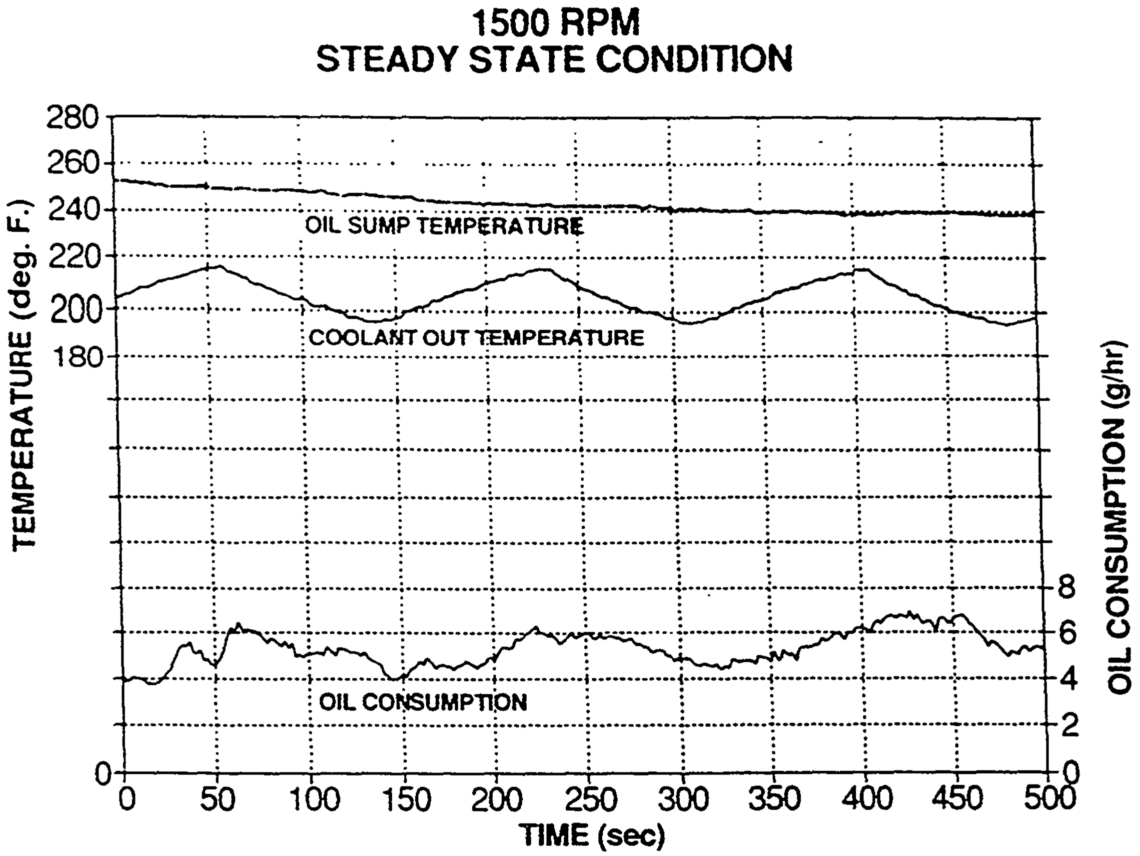


FIGURE 13

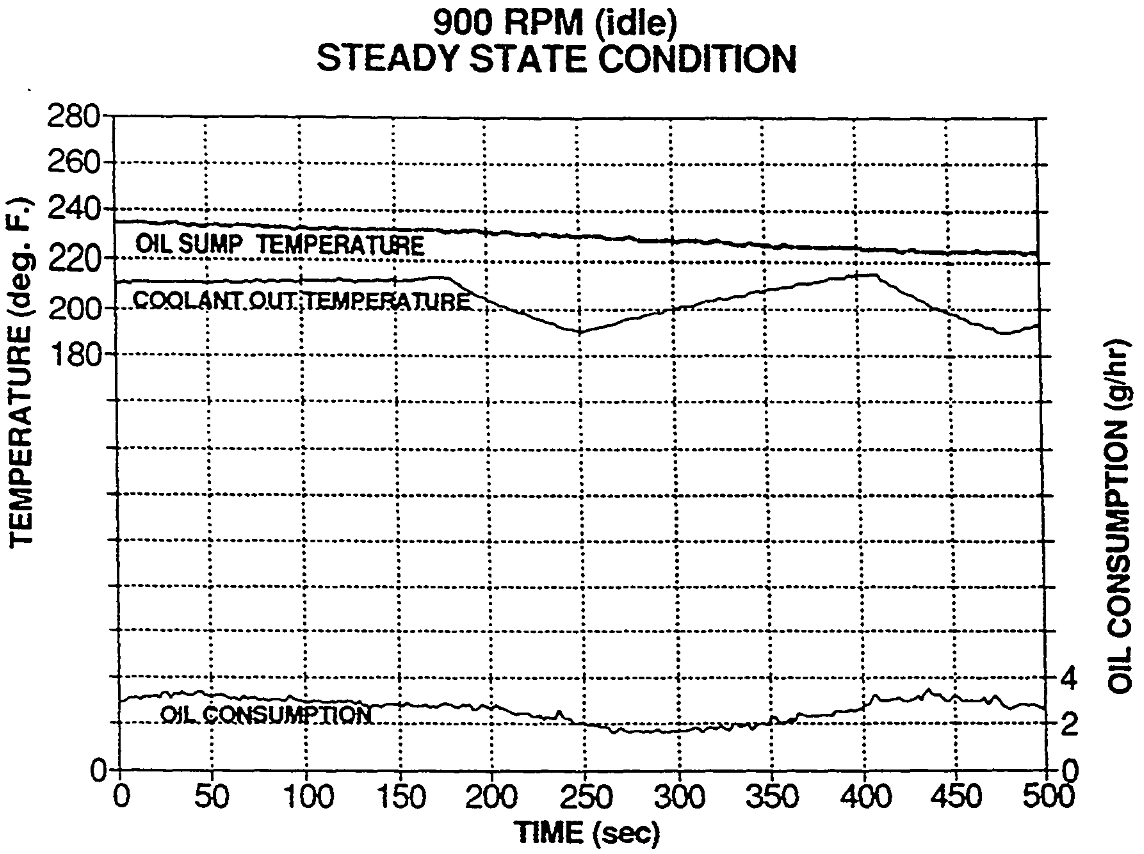


FIGURE 14

APPENDIX E

Final Oil Consumption Test Results from Southwest Research Institute

OIL CONSUMPTION MEASUREMENT FOR A METHANOL VEHICLE UNDER EMISSIONS CYCLE

SwRI Project No. 03-5461

Prepared for:

Dr. T. Maxwell
Professor
Department of Mechanical Engineering
Texas Tech Research Foundation
P.O. Box 43106
Lubbock, Texas 79409-3106

Prepared by:

Susumu Ariga

Approved:

SMShahed

S. M. Shahed
Director
Department of Engine Research
Engine and Vehicle Research Division

EXECUTIVE SUMMARY

Methanol-fueled engines have a higher wear rate of power cylinder components, especially when the vehicle is operated under cold temperature conditions. Excessive components' wear may increase blowby gas flow and oil consumption. Oil deterioration is, then, accelerated and an increased amount of lubricant additives emits to the exhaust system, contributing to the catalyst deactivation.

The objective was to measure the oil consumption of a methanol-fueled vehicle under the conditions of the EPA dynamometer urban driving cycle test procedure. The Southwest Research Institute (SwRI) developed on-line oil consumption measurement system was employed to accomplish the real-time measurement of oil consumption under transient operating conditions. Oil consumption was measured before and after the vehicle accumulated a driving distance of more than 20,000 miles under city driving conditions and was compared to evaluate the effect of the durability test.

The oil consumption rate (g/hr) increased during the durability test. The degree of the increase varied, depending on the measurement conditions under either a cold- or hot-start test. The average oil consumption rate measured under the cold-start transient test conditions increased by 26 percent and that measured under the hot-start transient conditions increased by 9 percent.

Oil consumption over the duration of the EPA urban cycle (~1400 seconds) was significantly higher (52 percent) under the hot-start conditions than under the cold-start conditions. This trend was the same, regardless of pre- or post-durability testing, although the difference measured in the post-durability test was lower (31 percent).

Oil consumption of the post-durability test measured under steady-state conditions significantly increased (223 percent) when the engine speed was relatively high, e.g., 2950-rpm.

Whether the level of increase is high or low is not certain because there was no oil consumption data obtained for the gasoline engine under the same test procedure. Therefore, it is recommended that oil consumption of the gasoline engine be measured for comparison. A comprehensive test is recommended to understand the relationship between oil consumption, catalyst efficiency, and lubricant additives trapped in the catalyst in order to determine the significance of oil consumption increase for a long driving distance. Further investigation will be necessary to explain the high increase in oil consumption measured under a steady-state condition after the durability test has been completed.

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LIST OF FIGURES

1.0 BACKGROUND

Wear of the power cylinder components of a methanol engine is higher than that of a gasoline engine, especially under cold temperature operating conditions. The primary reason is the corrosiveness of methanol combustion products formed in the crevices of the piston and ring pack. A large degree of component wear increases blowby and oil consumption in a relatively short time. A high blowby increases the rate of lubricant deterioration. An increased oil consumption accelerates the catalyst deactivation due to chemical poisoning caused by the lubricant additives. Specially-formulated lubricant additives are normally used to reduce the wear of a methanol engine's components. However, there has not been test data available to show the level of oil consumption increases caused by component wear, especially those under transient operating conditions.

2.0 OBJECTIVE

The objective is to measure the oil consumption of a methanol vehicle on chassis dynamometer under the EPA dynamometer urban driving cycle test procedure before and after the vehicle durability test has been completed.

3.0 TEST APPARATUS AND PROCEDURE

The SwRI-developed on-line oil consumption measurement system has been used to measure oil consumption under step transients. The sampling gas pressure was manually controlled to maintain a certain level to achieve an acceptable measurement accuracy. It is impossible to manually adjust the sampling gas pressure under the EPA's transient cycle. Thus, the gas sampling technique was refined with an electronic, closed-loop control system. The sampling gas pressure was maintained at constant, regardless of speed and load change. This provision achieved the accuracy of the oil consumption measurement under transient conditions.

In order to prepare for oil consumption testing, the methanol-fueled vehicle (GM Corsica 2.8 liter V6 engine) was instrumented for flow rates of intake air and fuel, and engine pertinent temperatures and pressures. A laminar flow element (LFE) with pressure transducers was used for the intake air flow measurement in real-time, and a micro-motion, real-time mass fuel flow meter was used for fuel flow measurement. An exhaust gas sampling probe was fitted to the exhaust pipe close to the manifold flange. The standard oil was drained, saved, and a zero sulfur synthetic oil was installed. The vehicle was, then, driven at normal operating temperatures to mix the zero sulfur oil with any residue of the original oil. This process was repeated through three changes of zero sulfur oil to insure that any sulfur residue from the original oil had been flushed from the system.

The vehicle was installed on the chassis dynamometer and tested to establish baseline performance of the oil consumption instrumentation with zero sulfur oil in the vehicle. The zero sulfur oil was then drained and replaced, for the balance of the testing, with an oil of known sulfur concentration that has proven to be thermally stable in maintaining the fixed concentration throughout the testing cycle.

The EPA urban dynamometer driving test cycle was performed on the vehicle from cold-start conditions, followed by a repeat of the cycle from hot-start conditions. The total length of the test is approximately 60 minutes, including soaking time, and the actual vehicle operating time was 40 minutes. In addition, the vehicle was operated under three steady-state conditions to obtain additional oil consumption information from this particular vehicle. The same tests were repeated after the vehicle was returned from the field test. The results are discussed below.

4.0 DISCUSSION OF THE TEST RESULTS

The Effect of a 21,000 Mile Durability Test: Figures 1 and 2 show plots of cumulative oil consumption in gram and vehicle speed during two test cycles. Each figure also shows the results obtained before (9,260 miles) and after the durability test (31,050 miles) was completed. The effect of the durability test (21,790 miles) was significant when the test was conducted under the cold-start conditions. Oil consumption increased by 26 percent after the durability test was completed. Under the hot-start conditions, the increase, due to the durability test, was 9 percent.

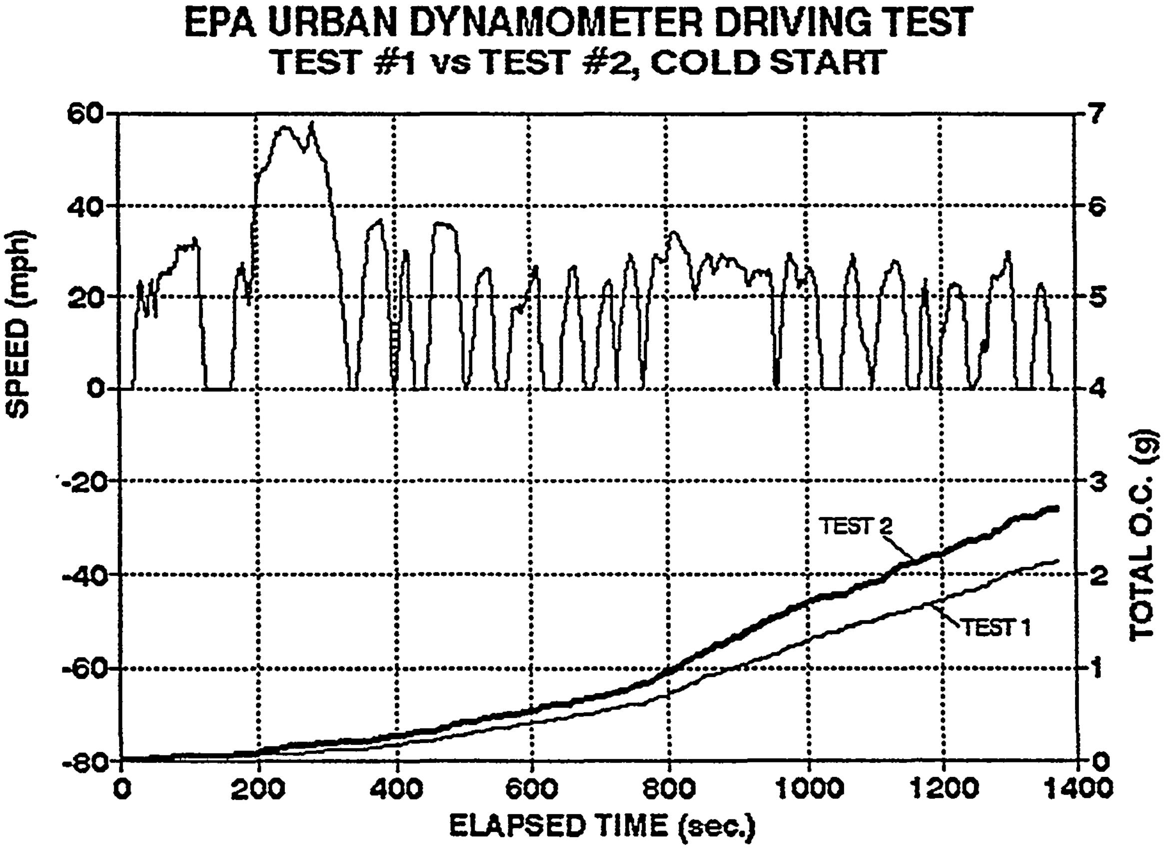

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FIGURE 1. OIL CONSUMPTION MEASURED UNDER COLD-START EPA URBAN DYNAMOMETER DRIVING TEST CYCLE

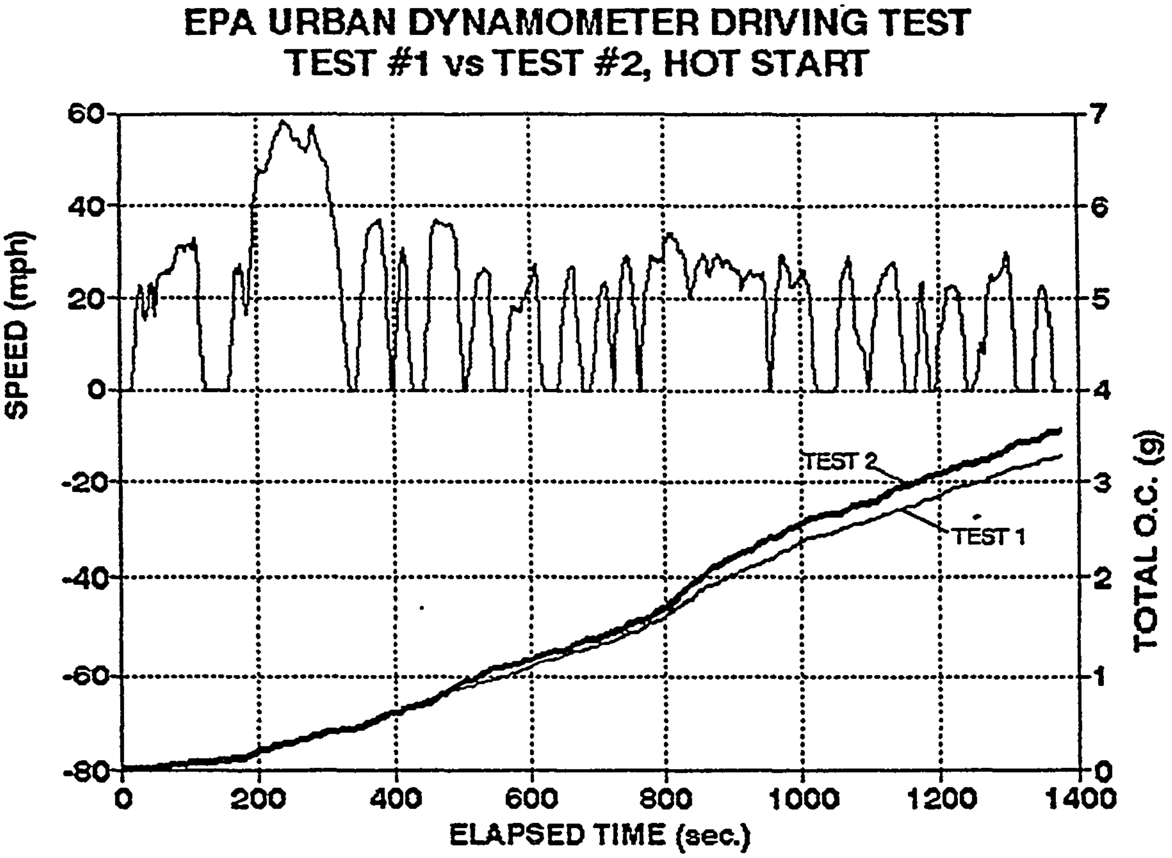

FIGURE 2. OIL CONSUMPTION MEASURED UNDER HOT-START EPA URBAN DYNAMOMETER DRIVING TEST CYCLE

The Effect of Cold- and Hot-Start: The difference in oil consumption between cold- and hot-start was high and the trend was the same, regardless of the pre- and the post-durability test, e.g., 52 and 31 percent, respectively. Figure 3 compares the average oil consumption rate in g/hr between cold- and hot-start and that between pre- and post-durability test.

Coolant temperature of the first 800 seconds was quite different between the cold and the hot-start test as shown in Figure 4. Thus, the difference in oil consumption between cold- and hot-start could primarily be caused by the difference in component temperatures. Low viscosity oil at high component temperature increases oil flow through the ring pack, while it decreases oil film thickness on the cylinder wall. The oil flow increase, due to the low viscosity, was probably significant enough to increase the amount of oil present in the cylinder compared to the oil volume reduction due to a reduced oil film thickness. Therefore, the amount of oil supplied to the combustion chamber likely increased, causing it to increase oil consumption under hot-start conditions. The trend of high oil consumption under hot-start conditions was the same, regardless of pre- and post-durability test.

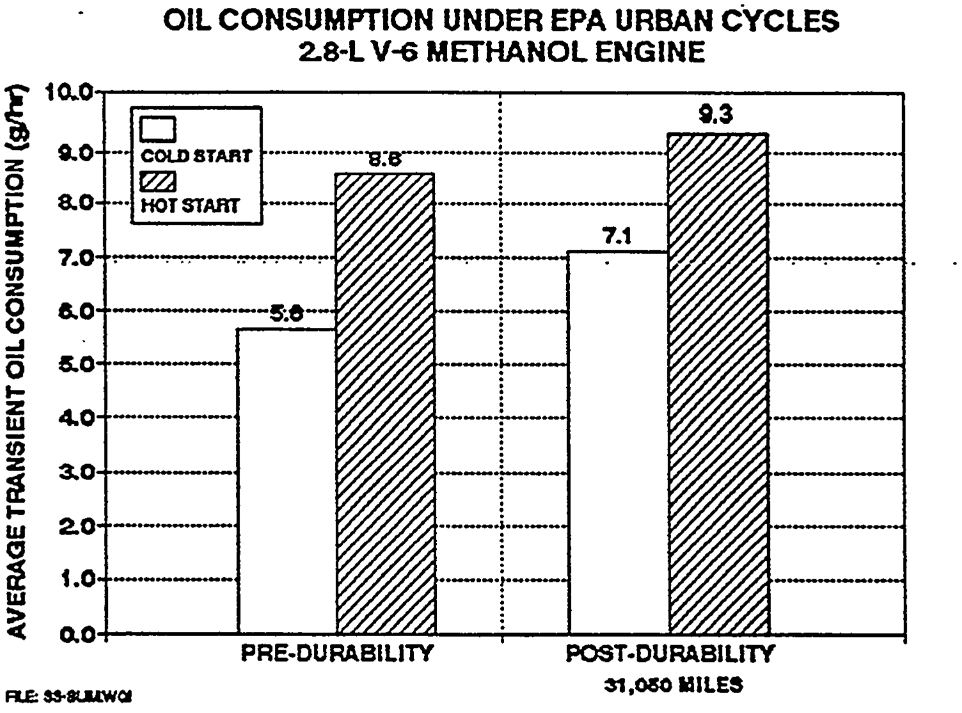

FIGURE 3. AVERAGE OIL CONSUMPTION RATE DURING TRANSIENT CYCLE

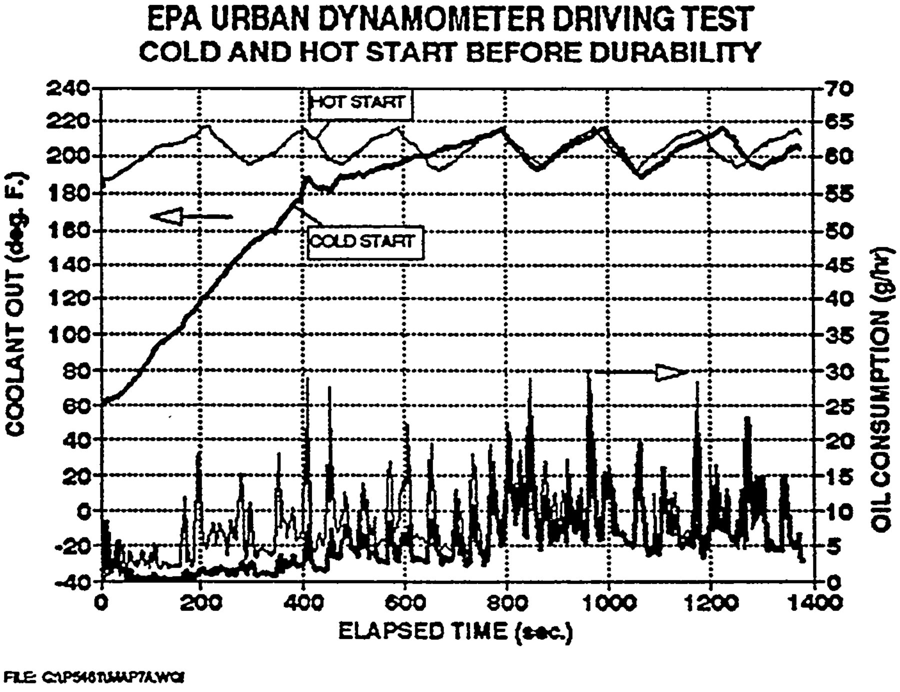

FIGURE 4. COOLANT TEMPERATURE DIFFERENCE BETWEEN COLD- AND HOT-START

Steady-State Tests: Following the transient cycle tests, three additional tests were performed under steady-state conditions. These were a 2675-rpm engine speed in fourth gear, 1500-rpm in fifth gear, and idle at 900-rpm. Results of these tests are presented in Figure 5. The increase in oil consumption of the post-durability test was significant at a higher engine speed. At 2675-rpm, the oil consumption of the post durability test was more than double (223 percent) compared to that of the pre-durability test. The rate of increase was significantly higher than that observed in the results obtained under transient cycles. A further investigation will be necessary to understand the differences observed between the steady-state and transient test results.

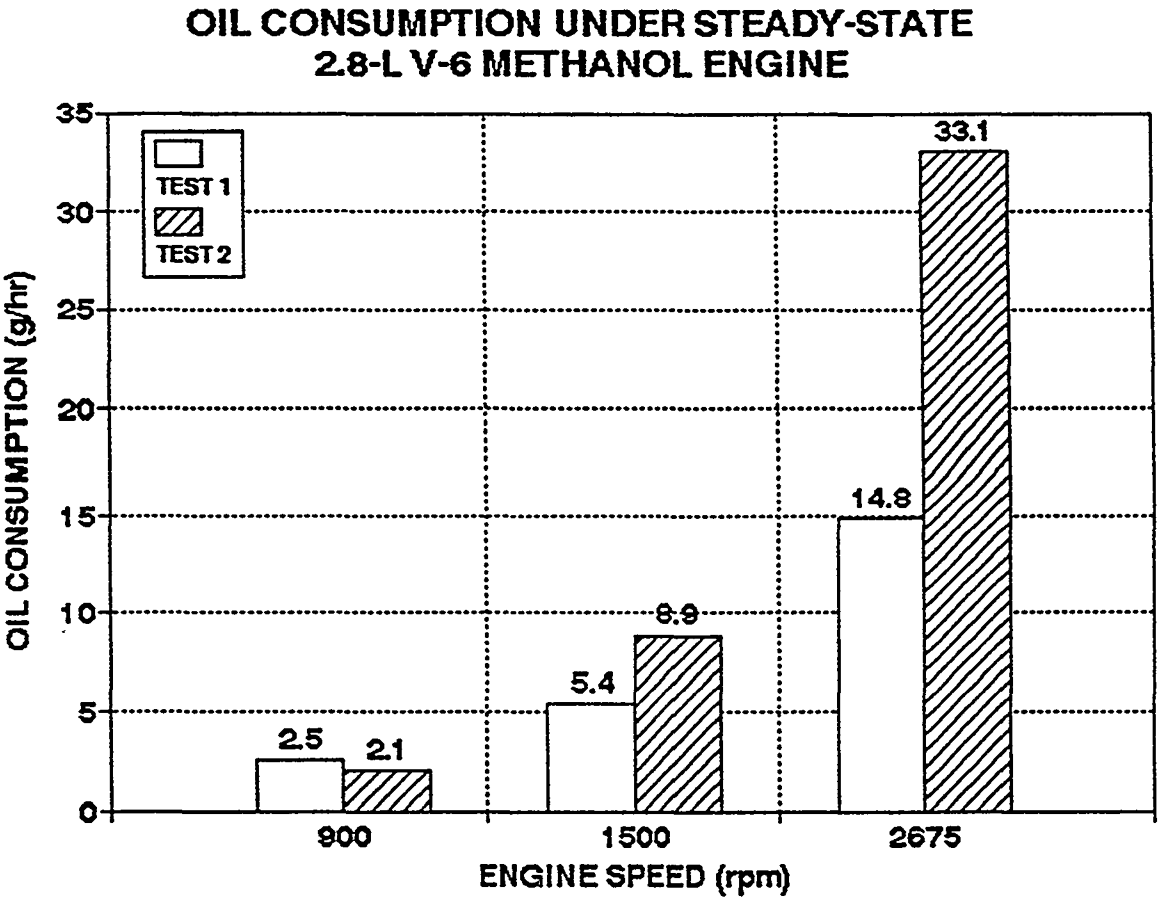

FIGURE 5. OIL CONSUMPTION UNDER STEADY-STATE CONDITIONS BEFORE (TEST 1) AND AFTER (TEST 2) THE DURABILITY TEST

Summary: Since there was no gasoline engine data, a comparison could not be made to determine the level of oil consumption increase measured in the methanol engine after the durability test was completed. However, a rough estimate of oil consumption over 100,000 miles can be made with the results obtained in this project. Oil consumption of the post-durability test (about 21,000 miles) increased by 9 to 26 percent, depending on whether there was a hot- or cold-start operating condition. In 100,000 miles, oil consumption could increase by 1.43 to 2.23 times, depending on cold- and hot-start, and on the assumption that the effect of component wear or other factors on the oil consumption increase remain the same throughout the 100,000 miles. The oil consumption rate, however, is likely to increase as the vehicle accumulates its mileage, and it increases exponentially rather than linearly. Thus, the oil consumption increase will probably be greater than the above estimate.

The impact of the oil consumption increase is catalyst poisoning. Figure 6 shows the data found in the referenced literature[1] regarding the relationship between hydrocarbon conversion efficiency of the catalyst and the amount of phosphorous contained in lubricating oil reaching the catalyst. Suppose the amount of phosphorous increased by a factor of 2 because oil consumption increase was twice the above estimate, the catalyst efficiency drops by about 10 percent. This may not appear significant; however, the increase in hydrocarbon emissions downstream of the catalyst becomes about 50 percent higher on the assumption that hydrocarbon emissions out of the engine do not change. In reality, the emissions out of the engine also increase as the vehicle accumulates miles. Therefore, the catalyst poisoning must be reduced. If engine oil no longer requires such additives as ZDDP, yet low component wear is warranted, the catalyst poisoning could be minimized. Otherwise, oil consumption should be reduced to a minimum level.

Research into the details of the relationship between oil consumption, catalyst efficiency, and additives accumulated reaching to the catalyst is one subject that should be considered for future research. The results will provide quantitative characterization of the effect of oil consumption on catalyst poisoning and will help to determine the level of oil consumption that should be targeted for future engines.

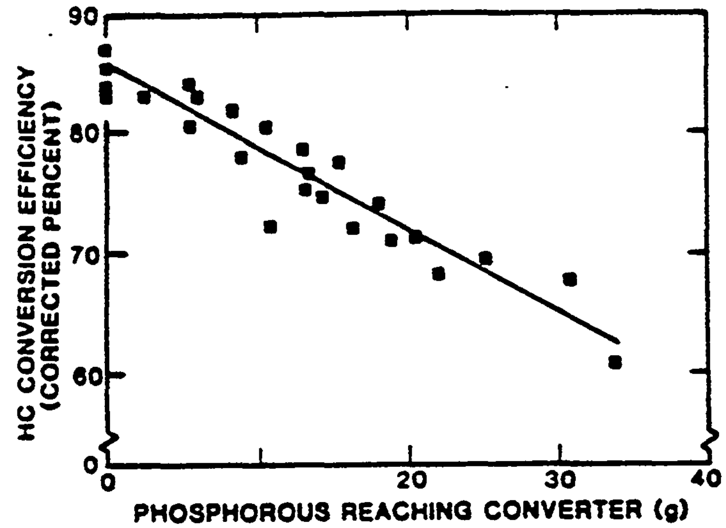

FIGURE 6. THE RELATIONSHIP BETWEEN HYDROCARBON CONVERSION EFFICIENCY AT A CATALYST AND THE AMOUNT OF PHOSPHOROUS REACHING THE CATALYST

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[1] J. A. Spearot and F. Carraciolo, "Engine Oil Phospherus Effects on Catalytic Converter Performance in Federal Durability and High Speed Vehicle Tests," SAE Transaction, Vol. 86, 1977.

5.0 CONCLUSIONS

1. Oil consumption of a methanol-fueled vehicle under the EPA urban driving test cycle w successfully measured with the sulfur tracer technique.

2. Vehicle durability tests of more than 20,000 miles increased oil consumption 26 percent under cold-start conditions and by 9 percent under hot-start conditions.

3. Oil consumption under hot-start conditions was higher than under cold-start conditio by as much as 56 percent.

4. The effect of component temperatures on oil viscosity appears to be the primary ca of high oil consumption under hot-start conditions.

5. Oil consumption under steady-state conditions significantly increased (223 percent) a 2675-rpm engine speed after the durability test was completed.

6.0 RECOMMENDATIONS

1. It is recommended that oil consumption of a gasoline-fueled vehicle be measured under conditions similar to those used for the methanol-fuel vehicle in order to normalize the effect of methanol operation on the oil consumption.

2. The relationship between oil consumption, catalyst efficiency, and additives trapped in the catalyst should be investigated by obtaining the measurement results of all three variables at the same time. The results will be useful in understanding whether catalyst poisoning due to lubricant additives is serious.

3. A further investigation will be necessary to understand the differences in the degree of oil consumption increase depending on steady-state and transient conditions.

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13. ABSTRACT *(Maximum 200 words)*

This report describes work performed by Texas Tech University to determine the effects of methanol fuel on engine performance a exhaust emissions during long-term use. Engine wear, gasket performance, fuel economy, emissions level, oil consumption, and overall vehicle performance were monitored over approximately 22,000 miles of vehicle operation. At the beginning of the prograr vehicle performance, oil consumption, and emissions baselines were established to be used for comparative purposes. The engin was removed from the vehicle and disassembled, and all bearing and ring clearances and cam profiles were measured to determir any preexisting wear. All gaskets, seals, bearings, and piston rings were replaced. The cylinder bore was honed, valve and valve seats were lapped, and the crankshaft journals were polished. Higher flow rate fuel injectors supplied by AC Rochester were installed, and the computer system was calibrated for M100 fuel. At the completion of the program, after the mileage accumulatior phase, the vehicle emissions level, oil consumption, and engine performance were again determined. The engine was removed fr the vehicle, disassembled, and engine component wear was determined and compared with the initial condition.

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