Sulfuric Acid Emissions from a Union Carbide Low Sulfate Catalyst

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Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

Background

To meet the emission levels required by the Clean Air Act, most vehicle manufacturers use oxidation catalysts as part of their vehicle's emission control system. By using a catalyst, the manufacturers have been able to calibrate their vehicles to achieve good fuel economy even while they have had to meet more stringent emission standards (1)*.

However, during tests in recent years, it was observed that small amounts of exhaust SO_2 were converted to sulfuric acid mist by oxidation catalysts (2,3). Because of the possible adverse health effects, EPA has undertaken efforts to develop sampling systems and test procedures (4) and to evaluate the sulfate emissions characteristics of various systems.

Laboratory tests of a metal oxidation catalyst by Union Carbide (UC) has shown promise for low sulfate emissions in a vehicle. In bench checks a large portion of the SO_2 injected had formed elemental sulfur after passing through the catalyst. Union Carbide offered several units to EPA for vehicle testing. ECTD, because of its interest in evaluating technology which could have an impact on sulfate emissions, agreed to test the catalysts.

The Environmental Protection Agency receives information about many systems which appear to offer potential for emissions reduction or improvement in fuel economy compared to conventional engines and vehicles. EPA's Emission Control Technology Division is interested in evaluating all such systems, because of the obvious benefits to the Nation from the identification of systems that can reduce emissions, improve economy, or both. EPA invites developers of such systems to provide to the EPA complete technical data on the system's principle of operation, together with available test data on the system. In those cases in which review by EPA technical staff suggests that the data available show promise for the system, attempts are made to schedule tests at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of all such tests are set forth in a series of Technology Assessment and Evaluation Reports, of which this report is one.

The conclusions drawn from the EPA evaluation tests are of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving improvements on the different types of vehicles that are in actual use requires a much larger sample of test vehicles than is economically feasible in the evaluation test projects conducted by EPA. For promising systems it is necessary that more extensive test programs be carried out.

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*Numbers in parenthesis designate reference listed at end of this report.

The conclusions from this EPA evaluation test can be considered to be quantitatively valid only for the specific test car used. However, it is reasonable to extrapolate the results from the EPA test to other types of vehicles in a directional or qualitative manner, i.e., to suggest that similar results are likely to be achieved on other types of vehicles.

System Description

The Union Carbide unit is a monolith metal oxidation catalyst. The active material is a non-noble metal ceramic material that is supported by a corrugated wire mesh (See Figure 1). A strip of the mesh and ceramic is rolled up lengthwise to form a cylindrical biscuit.

Since complete characteristics of the UC catalyst were unknown, a test vehicle was selected whose original equipment catalyst approximated the known general characteristics (space velocity, size, monolith) of the UC catalyst. Also, since studies had shown that catalyst vehicles with excess air have higher sulfate emissions (5), the test vehicle would have an air pump to provide a severe test of the UC catalyst's effectiveness.

A survey was conducted for a suitable vehicle. Included in the survey were cars made by Chrysler, Datsun, Ford, and Volkswagen. The 1975 Ford Pinto 2.3 litre, 49 State, catalyst vehicle was chosen as most compatible. Walker Manufacturing (a manufacturer of automotive mufflers and catalyst cans) volunteered their research facilities to fabricate a suitable container. They canned the biscuit in a package identical to the original. (The test vehicle is described in detail on page 4.)

Test Procedures

Exhaust emissions tests were conducted according to the 1975 Federal Test Procedure ('75 FTP), described in the Federal Register of November 15, 1972 except that no evaporative emissions tests were conducted. Additional tests included the EPA Highway Fuel Economy Test (HFET), described in the Federal Register, Volume 39, Number 200, October 15, 1974, the sulfate cycle, and steady state emissions tests. All tests were conducted using an inertia weight of 3000 pounds (1360 kg) with a road load setting of 10.3 horsepower (7.7 kW) at 50 miles per hour (80.5 km/hr).

The sulfate procedure employed a test series consisting of a 75 FTP, an EPA Highway cycle, and several sulfate cycles (see attachment). All testing was done using a fuel doped to a level of .03 percent sulfur with di-tertiary butyl disulfide. The vehicle was preconditioned by driving either 500 miles (monolith catalyst) or 1000 miles (pelleted catalyst) of the AMA durability cycle while using the sulfurized fuel. To permit the catalyst to age, the UC catalyst was driven 2000 miles before sulfate testing was initiated.

The vehicle was tested in three configurations: no catalyst, factory catalyst, and UC catalyst. All three units were similar (See Figure 2).

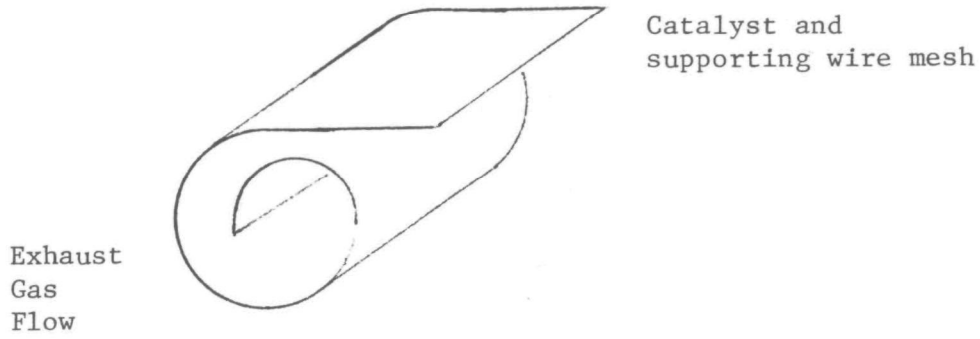

Figure 1 Union Carbide Catalyst Biscuit

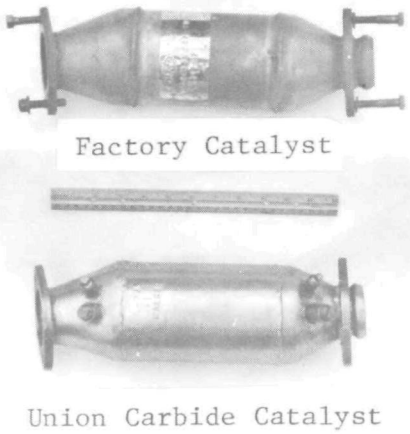

Figure 2A Catalysts

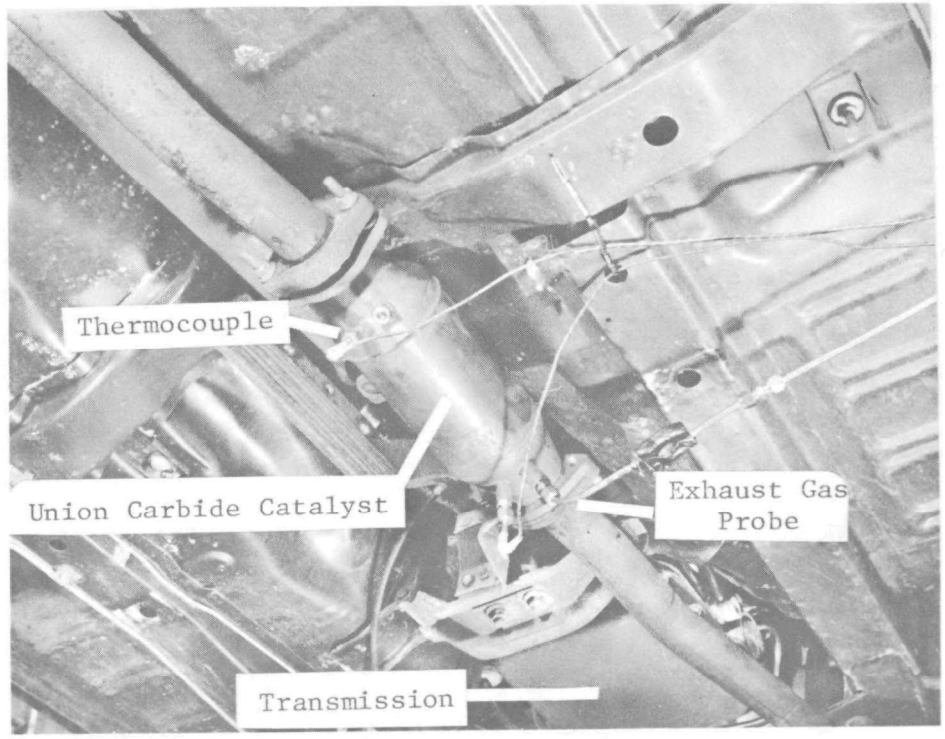

Figure 2B Catalyst Installation

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1976 Ford Pinto
Emission control system - Catalyst

Engine

type	4 stroke, Otto cycle, inline 4 cylinder
bore x stroke	3.78 x 3.13 in./96.0 x 79.5 mm
displacement	140 cu. in./2300 cc
compression ratio	9.0:1
maximum power @ rpm	88 hp/65.6 kW
fuel metering	single 2 barrel carburetor
fuel requirement	regular unleaded, tested with 96 RON Indolene HO unleaded with .03% sulfur (by weight)

Drive Train

transmission type	3 speed automatic
final drive ratio	3.18:1

Chassis

type	unitized body/frame, front engine, rear drive
tire size	A 78 x 13
curb weight	
inertia weight	3000 pounds
passenger capacity	4

Emission Control System

basic type	air injection EGR factory catalyst monolith 3.64 in. diameter x 6 in. long effective volume 52 cu. in. Corning-substrate Engelhard-catalyst Walker-container Union carbide catalyst monolith 4 in diameter x 3 in. long effective volume 37 cu. in. UC substrate UC catalyst
Durability accumulated on system	3480 miles with factory catalyst 2200 miles with UC catalyst

An empty catalyst can was used to permit baseline vehicle emissions to be established. These values were then used to evaluate the efficiency of the two catalysts.

The UC catalyst was equipped with temperature probes (See Figure 2), to allow test personnel to determine if and when catalyst lightoff occurred.

Test Results

The Union Carbide catalyst performed well. As a catalyst it achieved smaller reductions in HC and CO emissions than the factory catalyst (see summary results below), but the vehicle easily met the 1976 emission standards. The sulfate emissions were repeatable, stable, and unexpectedly low (see summary results below) particularly for a vehicle using an air pump. The detailed results are tabulated in Tables 1 through 4.

Emissions tests were conducted at low mileage to verify the satisfactory operation of the UC catalyst. This also permitted the catalyst deterioration to be observed. The results for the 75 FTP and HFET are tabulated below:

Low Mileage '75 FTP Composite Mass Emissions
grams per mile
(grams per kilometre)

	System Mileage (kilometres)	HC	CO	CO_2	NOx	Fuel Economy (Fuel Consumption)
Baseline (2 test)	2870 (4623)	1.33 (.83)	21.52 (13.37)	365 (227)	2.04 (1.26)	22.0 miles/gal (10.7 litres/100 km)
Factory Catalyst (1 test)	2713 (4366)	.37 (.23)	2.46 (1.53)	420 (261)	2.11 (1.31)	20.9 miles/gal (11.3 litres/100 km)
UC Catalyst (2 test)	328 (527)	.67 (.42)	5.54 (3.44)	396 (246)	1.71 (1.06)	21.8 miles/gal (10.8 litres/100 km)
Factory Catalyst % Change from Baseline		-72%	-89%	15%	-3%	-5%
UC Catalyst % Change from Baseline		-50%	-74%	8%	-16%	-1%

On the EPA Highway Cycle the results were:

Mass Emissions
Low Mileage EPA Highway Fuel Economy Test
grams per mile
(grams per kilometre)

	System Mileage (kilometres)	HC	CO	CO_2	NOx	Fuel Economy (Fuel Consumption)
Baseline (2 tests)	2894 (4657)	.78 (.48)	2.31 (1.44)	267 (166)	2.47 (1.53)	32.5 miles/gal (7.4 litres/100 km)
Factory Catalyst (1 test)	2734 (4400)	.16 (.10)	.16 (.10)	299 (186)	2.76 (1.72)	29.6 miles/gal 8.0 litres/100 km)
UC Catalyst (1 test)	344 (554)	.40 (.25)	1.03 (.64)	287 (178)	2.90 (1.80	30.6 miles/gal (7.7 litres/100 km)
Factory Catalyst % Change from Baseline		-79%	-93%	12%	12%	-9%
UC Catalyst % Change from Baseline		-49%	-55%	7%	17%	-6%

Thus, the UC catalyst achieved significant reductions in HC and CO emissions, at low mileage. However, as an oxidation catalyst it was not as efficient as the factory unit.

The vehicle then underwent mileage accumulation to age the UC catalyst. The factory catalyst later underwent mileage accumulation to precondition the factory unit prior to sulfate tests.

The results of the sulfate tests were:

'75 FTP Composite Mass Emissions
grams per mile
(grams per kilometre)

	System Mileage (kilometres)	HC	CO	CO_2	NOx	Fuel Economy (Fuel Consumption)
Baseline	5202 (8372)	1.49 (.93)	14.74 (9.16)	383 (238)	2.02 (1.26)	21.6 miles/gal (10.9 litres/100 km)
Factory Catalyst	3386 (5449)	.35 (.21)	2.70 (1.68)	386 (240)	1.90 (1.18)	22.7 miles/gal (10.4 litres/100 km)
U.C. Catalyst	2088 (3360)	.82 (.51)	4.80 (2.98)	375 (234)	1.98 (1.23)	22.8 miles/gal (10.3 litres/100 km)
1975-76 Federal Standards		1.5	15.0		3.1	
Factory Catalyst % Change from Baseline		-77%	-82%	1%	-6%	5%
UC Catalyst % Change from Baseline		-45%	-67%	-2%	-2%	6%

The corresponding EPA Highway Fuel Economy Test results were:

EPA Highway Fuel Economy Test
Mass Emissions
grams per mile
(grams per kilometre)

	System Mileage (kilometres)	HC	CO	CO_2	NOx	Fuel Economy (Fuel Consumption)
Baseline	5224 (8406)	.90 (.56)	2.10 (1.30)	298 (185)	2.22 (1.38)	29.1 miles/gal (8.1 litres/100 km)
Factory Catalyst	3425 (5512)	.17 (.11)	18 (.11)	303 (188)	2.48 (1.54)	29.3 miles/gal (8.0 litres/100 km)
UC Catalyst	2126 (3432)	.45 (.28)	.85 (.53)	292 (181)	2.59 (1.61)	30.1 miles/gal (7.8 litres/100 km)
Factory Catalyst % Change from Baseline		-82%	-91%	+2%	12%	1%
UC Catalyst % Change from Baseline		-50%	-60%	-2%	17%	3%

In these tests after 5000 durability miles the UC catalyst again achieved significant reductions in HC and CO emissions, although it was not as efficient as the factory unit. The percent change in HC and CO emission reductions remained constant for each catalyst. Thus, on the basis of this limited data, the UC catalyst has no readily apparent deterioration problem. The sulfate results for the above tests are listed in Tables 2 and 3. They are not noted above because the sulfate emissions over the '75 FTP and the EPA Highway Cycle are not representative of a vehicle's sulfate emissions over the sulfate emission test cycle.

The principle thrust of this report, the vehicle's sulfate emissions over the sulfate cycle, are summarized below and tabulated in Table 4:

Sulfate Cycle Sulfate Emissions

System Mileage		H_2SO_4 mgm/mile
Factory Catalyst	3423 (5508)	27.5 (range 20.6-39.4)
UC Catalyst	2116 (3405)	6.1 (range 3.2-8.2)

For comparison, typical vehicle* sulfate emission results (5) as found in the EPA sulfate baseline study were:

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* Vehicles calibrated to meet present and future emission standards.

System Mileage	H_2SO_4 mgm/mile
Catalyst vehicles with excess air	30 (range 0.3-96)
Catalyst vehicles without excess air	17 (range 0.5-83)
3-way catalyst vehicles	1
Non-catalyst vehicles	1

The UC catalyst sulfate emissions were stable and low, particularly for a vehicle using an air pump.

Steady State fuel economy results in miles per gallon, were:

Speed, mph	Baseline	Factory Catalyst	UC Catalyst
15	24.2	26.5	27.2
30	32.9	32.9	32.8
45	33.3	33.1	33.1
60	29.6	28.4	28.6

Thus there was no significant steady state fuel economy difference among the three configurations.

A comparison of the test vehicle's combined city/highway fuel economy, with that of the 1976 certification Pinto (as published in the 1976 EPA Buyer's Guide), showed no fuel economy peralty. When compared to all vehicles in the same inertia weight class (3000 lbs) the test vehicle and the certification vehicle had an 8% fuel economy improvement.

Vehicle	City/Highway Combined Fuel Economy miles/gal	(Fuel Consumption) litres/100 km
Test Pinto, Baseline	24.5	(9.6)
Test Pinto, Factory Catalyst	25.3	(9.3)
Test Pinto, U.C. Catalyst	25.6	(9.2)
Ford Certification Vehicle (140 CID)	25.7	(9.1)
Average of all 3000 lb Vehicles (avg. 150 CID)	23.6	(10.0)

In calculating city/highway combined fuel economy, the urban fuel economy is weighted 55% and the highway fuel economy is weighted 45% to account for the 55/45 ratio of urban to rural mileage accumulation.

$$MPG_{combined} = \frac{1}{\frac{.55}{MPG_{urban}} + \frac{.45}{MPH_{highway}}}$$

The vehicle had good driveability.

Conclusions

The Union Carbide catalyst performed well. As an oxidation catalyst it achieved smaller reductions in HC and CO emissions than the factory catalyst. The sulfate emissions were repeatable, stable, and unexpectedly low, particularly for a vehicle using an air pump. However an increase in catalyst size to achieve comparable emission reductions might change sulfate emissions.

References

1. T. C. Austin, R. B. Michael, and G. R. Service, "Passenger Car Fuel Economy Trends through 1976", SAE paper 750957, presented at Automobile Engineering Meeting, Detroit, Michigan, October 1975.

2. W. R. Pierson, R. H. Hammerle, J. T. Kummer, "Sulfuric Acid Aerosol Emissions from Catalyst-Equipped Engines." SAE Publication Number 740287, Detroit, Michigan, February 1974.

3. R. L. Bradow, John B. Moran, "Sulfate Emissions from Catalyst Cars, A Review," SAE Publication Number 750090, Detroit, Michigan, February 1975.

4. J. H. Somers, R. Lawrence, C. E. Fett, T. M. Baines, and R. J. Garbe, "Sulfuric Acid Emission from Light Duty Vehicles," SAE paper 760034, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

5. Internal report "Test Report, Automotive Sulfuric Acid Baseline Program," EPA, Emission Control Technology Division, January 1976.

Attachment

Ford Pinto
Procedures used to measure Sulfate Emissions

1. The fuel was drained from the test vehicle. The vehicle was refueled with Indolene HO gasoline containing .030% sulfur by weight.

2. The catalyst was stabilized by driving 500 miles of the AMA durability cycle to stabilize the sulfate loading of the catalyst.

3. The following sequence of test cycles was used to measure sulfate emissions.

a) 75 FTP
b) Sulfate emission test
c) Sulfate emission test
d) EPA Highway driving cycle
e) Sulfate emission test
f) Sulfate emission test.

Table 1A
Baseline '75 FTP Mass Emissions
grams per mile

			Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag 3 Hot Transient				
Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3118	2852	2852	1.95	33.76	375	2.70	20.5	1.24	24.98	373	1.38	21.3	1.18	12.78	351	2.68	23.7
76-3125	2893	2893	1.71	28.60	373	2.71	21.0	1.20	21.29	365	1.43	22.1	1.15	9.49	351	2.79	24.0
77-129	5197	5197	1.84	26.92	404	2.67	19.6	1.38	14.25	390	1.59	21.3	1.41	6.77	361	2.52	23.6
77-149	5208	5208	1.91	28.38	405	2.58	19.5	1.34	13.18	385	1.51	21.6	1.50	7.12	355	2.40	23.9

Table 1B
Factory Catalyst '75 FTP Mass Emissions
grams per mile

			Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag 3 Hot Transient				
Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3099	2713	2713	.90	10.64	434	2.70	19.5	.20	.21	420	1.51	20.6	.31	.58	390	2.81	22.6
77-212*	5799	3348	.85	14.54	425	2.53	19.7	.20	.20	382	1.41	23.2	.30	.73	358	2.34	24.7
77-247*	5875	3424	.70	8.62	443	2.62	19.4	.19	.24	389	1.37	22.8	.32	.78	342	2.39	25.8

* Sulfate emissions taken.

Table 1C
Union Carbide '75 FTP Mass Emissions
grams per mile

			Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag 3 Hot Transient				
Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOX	Fuel Economy MPG
76-3321	3245	321	1.26	1[illegible].07	430	1.12	19.4	.51	3.56	421	1.44	20.7	.57	3.00	370	1.10	23.5
76-3313	3258	334	1.10	12.40	412	2.95	20.4	.53	3.68	385	1.49	22.6	.56	3.03	352	2.74	24.8
76-3518*	4934	2010	1.23	12.79	418		20.1	.87	.80	397	2.82	22.1	1.08	2.69	375	1.79	23.2
76-3534*	5009	2085	1.06	14.36	400	2.49	20.8	.60	3.29	364	1.33	23.9	.73	3.54	342	2.24	25.4
76-3577*	5093	2169	1.03	13.07	387	2.70	21.6	.60	3.11	364	1.64	23.9	.71	2.42	346	2.65	25.2

* Sulfate emissions taken.

Table 2A
Baseline '75 FTP Composite Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3118	2852	2852	1.37	23.46	367	2.01	21.7
76-3125	2893	2893	1.29	19.57	363	2.06	22.3
77-129	5197	5197	1.48	14.82	385	2.07	21.5
77-149	5208	5208	1.50	14.66	381	1.97	21.7

Table 2B
Factory Catalyst '75 FTP Composite Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4*	% Conversion
76-3099	2713	2713	.37	2.46	420	2.11	20.9		
77-212	5799	3348	.36	3.29	384	1.90	22.7	19.7	15
77-247	5875	3424	.33	2.11	387	1.90	22.7	9.7	7.3

* mgm per mile H_2SO_4, values normalized to .030% sulfurized fuel.

Table 2C
Union Carbide Catalyst '75 FTP Composite Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4	% Conversion
76-3321	3245	321	.68	5.78	409	1.28	21.1		
76-3313	3258	334	.66	5.30	382	2.13	22.6		
76-3518	4934	2010	1.00	3.79	395		22.0	2.4	1.9
76-3544	5009	2085	.73	5.64	365	1.82	22.6	2.1	1.7
76-3577	5093	2169	.72	4.97	364	2.13	23.7	.71	.6

* mgm per mile H_2SO_4, values normalized to .030% sulfurized fuel.

Table 3A
Baseline Highway Cycle Mass Emission
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3118	2873	2873	.79	2.98	266	2.49	32.5
76-3125	2915	2915	.76	1.64	268	2.45	32.5
77-129	5206	5206	.90	2.15	305	2.34	28.5
77-149	5241	5241	.90	2.04	291	2.09	29.8

Table 3B
Factory Catalyst Highway Cycle Mass Emissions
grams per mile

Test Number	Vehicle Mileage	Vehicle Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4*	% Conversion
76-3099	2734	2734	.16	.16	299	2.76	29.6		
77-215	5837	3386	.17	.17	302	2.41	29.3	33.0	37.4
77-250	5915	3464	.17	.18	303	2.55	29.2	38.3	43.8

* mgm per mile H_2SO_4, values normalized to .030% sulfurized fuel.

Table 3C
Union Carbide Catalyst Highway Cycle Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4*	% Conversion
76-3313	3268	344	.40	1.03	287	2.90	30.6		
76-3521	4971	2047	.52	.88	303		29.0	8.2	9.2
76-3547	5049	2125	.42	.93	302	2.76	29.1	4.2	4.7
76-3580	5130	2206	.42	.75	271	2.42	32.4	9.8	12.3

* mgm per mile H_2SO_4, values normalized to .030% sulfurized fuel.

Table 4A

No sulfate emissions taken on vehicle without catalyst.

Table 4B
Factory Catalyst Sulfate Cycle Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4*	% Conversion
77-213	5810	3359	.19	.33	333	2.50	26.6	20.6	21.2
77-214	5823	3372	.19	.23	322	2.51	27.5	23.2	24.7
77-216	5847	3396	.17	.27	332	2.50	26.6	25.9	26.7
77-217	5860	3409	.16	.28	325	2.46	27.2	30.4	32.0
77-248	5886	3435	.17	.29	321	2.52	27.5	21.9	23.3
77-249	5901	3450	.17	.32	333	2.59	26.5	29.4	30.1
77-251	5925	3474	.17	.28	324	2.46	27.3	39.4	41.7
77-252	5938	3487	.18	.50	330	2.42	26.8	28.8	29.9

* mgm per mile H_2SO_4, values normalized to .030% sulfurized fuel.

Table 4C
Union Carbide Catalyst Sulfate Cycle Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4*	% Conversion
76-3519	4945	2021	.61	1.81	340		25.7	6.0	5.0
76-3520	4958	2034	.60	1.68	323		27.1	3.2	3.4
76-3522	4981	2057	.63	1.24	307		28.5	5.2	5.8
76-3523	4994	2070	.63	1.45	313		28.0	6.9	7.5
76-3545	5020	2096	.42	1.71	303	2.40	28.9	4.1	4.7
76-3546	5035	2111	.43	1.47	312	2.61	28.1	5.2	5.6
76-3548	5059	2135	.45	1.63	309	2.64	28.4	8.2	9.7
76-3549	5072	2148	.43	1.58	291	2.47	30.1	6.0	7.0
76-3578	5104	2180	.44	1.35	292	2.41	30.0	6.7	8.0
76-3579	5117	2193	.44	1.37	282	2.22	31.0	6.8	8.4
76-3581	5140	2116	.44	1.32	298	2.41	29.4	7.3	8.4
76-3582	5153	2229	.45	1.31	304	2.33	28.8	7.3	8.1

* mgm H_2SO_4 per mile, values normalized to .030% sulfurized fuel.

Table 5A
Baseline Steady State Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	Speed MPH	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3119*	2813		Idle N	.11	2.98	56	.02	29.3
76-3120*	2814		Idle D	.21	6.10	49	.02	30.0
76-3121	2816		15	.64	24.35	326	.26	24.2
76-3122	2821		30	.77	23.53	230	2.04	32.9
76-3123	2828		45	.79	3.00	259	1.17	33.3
76-3124	2839		60	.65	1.05	296	3.81	29.6

* grams per minute, gallons per hour

Table 5B
Factory Catalyst Steady State Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	Speed MPH	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3100*	2748	2748	Idle N	.02	.01	63	.03	.42
76-3101*	2751	2751	Idle D	.03	.01	63	.03	.43
76-3102	2753	2753	15	.10	.11	334	.28	26.5
76-3103	2756	2756	30	.10	.09	269	2.53	32.9
76-3104	2797	2797	45	.13	.09	267	1.24	33.1
76-3105	2770	2770	60	.16	.14	312	3.90	28.4

* grams per minute, gallons per hour

Table 5C
Union Carbide Catalyst Steady State Mass Emissions
grams per mile

Test Number	Vehicle Mileage	System Mileage	Speed MPH	HC	CO	CO_2	NOx	Fuel Economy MPG
76-3322*	3277	353	Idle N	.04	.36	60	.03	.41
76-3323*	3277	353	Idle D	.08	.72	54	.04	.38
76-3324	3278	354	15	.37	4.86	317	.25	27.2
76-3325	3281	357	30	.36	4.72	262	2.12	32.8
76-3326	3284	360	45	.39	1.05	295	1.04	33.1
76-3327	3292	368	60	.33	.81	308	3.68	28.6

* grams per mile, gallons per hour