EPA/AA/CTAB/86-01

Technical Report

Durability Evaluation of Aftermarket Catalysts

by

Robert I. Bruetsch
John Shelton

March 1986

NOTICE

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U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources
Emission Control Technology Division
Control Technology and Applications Branch
2565 Plymouth Road
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I. Introduction

Recently, aftermarket catalysts have been introduced into commerce by several companies. These catalysts appear to be different than OEM catalysts in one or more design features. These catalysts are also considerably less expensive than replacement OEM catalysts. The purpose of this project was to evaluate the efficiency of a group of aftermarket catalysts as a function of accumulated miles and to evaluate a single OEM catalyst at a single mileage point (83,161 miles) for comparison. Nine aftermarket catalysts were evaluated on one vehicle, which was provided by EPA. Catalyst evaluation was performed at Automotive Testing Laboratories, Inc. (ATL) in East Liberty, Ohio. Mileage was accumulated using other vehicles (five Impalas) by Hercules, Inc. of Cumberland, MD. The catalysts were evaluated for exhaust emissions conversion efficiencies and backpressure at each test point. This project was performed under Technical Directive No. 6 of EPA Contract No. 68-03-3230.

II. Test Vehicle

The test vehicle, which was supplied by EPA, was used for all emissions testing of all ten catalysts. The vehicle is a 1980 Oldsmobile Delta 88 four-door sedan with vehicle identification number (VIN) 3Y69YAM169068. It is equipped with power steering and power brakes, a 305 cubic-inch engine, and a 3-speed automatic transmission. Its emission control system includes air injection, oxidation catalyst, backpressure exhaust gas recirculation and early fuel evaporation (engine family 03L4F).

III. Catalysts Evaluated

Ten catalysts were tested. All ten are oxidation catalysts supplied by EPA. These include the OEM catalyst on the test vehicle supplied by EPA. The other nine catalysts include three nominally identical catalysts from three different aftermarket catalyst suppliers. EPA labeled each catalyst with a two-digit code, such as 1-2. This means the catalyst is from supplier number 1 (Walker) and is catalyst number 2 of 3 supplied by Walker. Catalyst 3-1 therefore is the first of three Brown catalysts. Catalysts are identified by this two-digit code in all documentation of this project, including this report. The converter suppliers and the catalyst code numbers are as follows:

Converter/Type		Code Numbers
1.	Walker/monolith	1-1,1-2,1-3
2.	Echlin/pellet	2-1,2-2,2-3
3.	Brown/monolith	3-1,3-2,3-3

IV. Test Sequences

A. Phase I: Baseline Emissions and Evaluation of Modal Testing

Catalyst conversion efficiency comparisons were generated two different ways. In the first method, conversion efficiency was calculated from a single test using the modal analyzer to measure engine-out and catalyst-out emissions. Bag data to measure tailpipe emissions was also generated. Catalyst-out emissions, as measured with the modal analyzer, were compared to the bag data. These measures were within 1.1 percent of each other based on a carbon balance analysis. In the second method, conversion efficiency was calculated from two separate tests; one run with the catalyst to yield tailpipe emissions, and the other run with a straight pipe installed in place of the catalyst to yield engine-out emissions. To achieve this objective, the test sequence shown in Table 1 was used.

Table 1

Baseline Test Sequence

	Cycle	Measure	Calculate
1.	FTP	HC, CO, NOx, CO_2 catalyst temperature (in & out), backpressure (catalyst in & out)	MPG, emissions (g/mi) by bag and for total test, pressure drop over catalyst
2.	Idle (5-min sample)	HC, CO, NOx, CO_2 catalyst temperature (in & out), backpressure (catalyst in & out)	Emissions (g/mim) pressure drop, fuel consumption (gal/min)
3.	20 MPH SS (5-min sample)	HC, CO, NOx, CO_2 catalyst temperature (in & out), backpressure (catalyst in & out)	Emissions (g/mi) pressure drop, MPG
4.	40 MPH SS (5-min sample)	HC, CO, NOx, CO_2 catalyst temperature (in & out) backpressure (catalyst in & out)	Emissions (g/mi) pressure drop, MPG
5.	60 MPH SS (5-min sample)	HC, CO, NOx, CO_2 catalyst temperature (in & out) backpressure (catalyst in & out)	Emissions (g/mi), pressure drop, MPG

The test sequence in Table 1 was run three times with the the test vehicle (Delta 88) using the OEM catlyst catalyst with the modal analyzer. Each time the modal analyzer was used, engine-out and tailpipe emissions were measured. The actual dynamometer horsepower (ADHP) was increased to 18.3 and the test sequence, less the FTP and idle cycles, was repeated twice using the OEM catalyst with the modal analyzer. Three more test sequences were then run with the OEM catalyst without the modal analyzer. The OEM catalyst was then removed and the test sequence was repeated three more times without the modal analyzer. The dynamometer horsepower settings were then increased and two more test sequences, less the FTPs and idles, were then run without the modal analyzer. This phase of testing is summarized as follows:

Number of Test Sequences	ETW/ADHP	Catalyst	Use Modal Analyzer?
3	4000/12.2	OEM	Yes
2 less FTPs and idles	4000/18.3	OEM	Yes
3	4000/12.2	OEM	No
2 less FTPs and idles	4000/18.3	OEM	No
3	4000/12.2	Straight Pipe	No
2 less FTPs and idles	4000/18.3	Straight Pipe	No

The results of these tests showed that the modal testing is preferable to the test sequences with the straight pipe. This decision was based on cost (one FTP per test with modal analyzer versus two FTPs per test; one with catalyst and one with straight pipe) and the fact that the pipe did not accurately represent backpressure caused by a catalyst thereby influencing imputed catalyst efficiency. EPA evaluated the data and informed the contractor to use the modal analysis method of generating data for subsequent phases of testing.

B. Phase 2: Zero-Mile Testing of Aftermarket Catalysts

The first aftermarket catalyst was installed on the test vehicle without mileage accumulation. After the exhaust system was checked and found free of leaks, the contractor completed two valid test sequences as shown previously in Table 1. The first catalyst was removed and the second aftermarket catalyst from the same manufacturer (Walker) was installed. Again the exhaust system was checked for leaks. Two additional valid test sequences were conducted. This catalyst was removed and the third Walker catalyst was installed. Two valid test sequences were then conducted with this catalyst. After all three Walker catalysts were tested at the zero mile test point, the same procedure was performed on the three Echlin and Brown catalysts. The vehicle odometer readings were recorded when each catalyst was installed or removed and at the start of each test cycle in the test sequence. Two test sequences, less FTPs and idles, were run on one catalyst from each manufacturer at the increased dynamometer horsepower setting (18.3 actual HP).

The resulting summary of testing for Phase 2: Zero-Mile Testing of Aftermarket Catalysts, is shown in Table 2. These sequences, as will be shown later, are exactly the same as those that were run at the 25K mileage point.

Table 2

Summary of Phase 2 Testing

Catalyst Manufacturer	Catalyst Number	Number of Sequences	No. of Sequences (less FTPs and idles) With Increased Dyno. HP
1	1	2	2
1	2	2	2
1	3	2	2
2	1	2	2
2	2	2	2
2	3	2	2
3	1	2	2
3	2	2	2
3	3	2	2

C. Phase 3: Mileage Accumulation and Testing at Higher Mileage Intervals

The aftermarket catalysts, which were removed from the test vehicle in Phase 2, were installed on other vehicles to accumulate mileage on the catalysts. The converters were installed on one of five nominally identical 1985 Chevrolet Impalas, equipped with V-8, 5.0-liter/305-CID engines and 700R4 automatic tranmissions. Mileage was accumulated over three of Hercules' standard test routes. These road routes are routinely used by Hercules for tire-wear testing, and are described below.

1. Route W-4

Route W-4 is characterized as a "slow wear" route. Its course consists entirely of dual-lane interstate expressways, about 15 percent in West Virginia and 85 percent in Maryland.

2. Route W-10-H

Route W-10-H is rated for what the tire industry considers as "medium wear." It consists almost entirely of interstate expressways, about 50 percent in Maryland and 50 percent in West Virginia. Compared to the slow wear route, this route's more extensive driving in mountainous terrain adds more turns and grades to the vehicle's duty cycle.

3. Route M-101

Route M-101 is a "high wear" route developed to simulate European driving. It splits about 60/40 percent Maryland/West Virginia and includes 250 miles of interstate expressway driving and 250 miles of mountainous driving which includes hard turns and grades up to 20 percent.

These three different routes can have potentially different effects on catalyst performance. Prior to the aftermarket catalyst aging on these routes, an instrumented Impala (one of the cars used later with the aftermarket catalysts) was used to profile the three routes. Engine rpm and the inlet and outlet temperatures of the vehicle's OEM catalysts were measured every 10 seconds. The catalyst temperature results obtained were as follows:

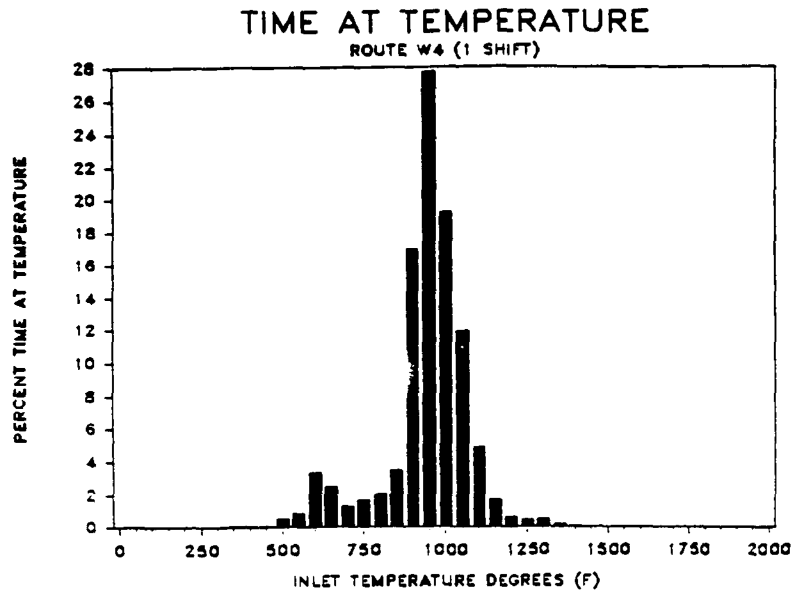
Average OEM Catalyst Temperature, °F

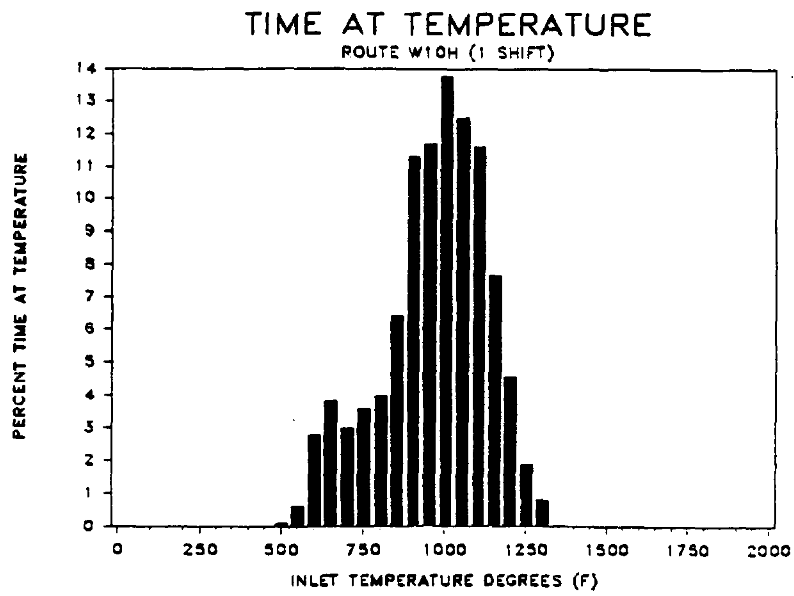
	Inlet	Outlet
Route W-4	941	939
Route W-10-H	965	1008
Route M-101	945	1004

Plots of the distributions of the catalyst inlet and outlet temperatures are shown in Figures 1 and 2, respectively.

The three different routes did not result in significantly different catalyst temperatures. The catalyst outlet temperature distributions are more similar to each other than are the inlet temperature distributions. Note that the "hardest" route in terms of tire wear did not produce the highest catalyst temperatures.

Figure 1 - Inlet Temperature Distributions of Durability Routes





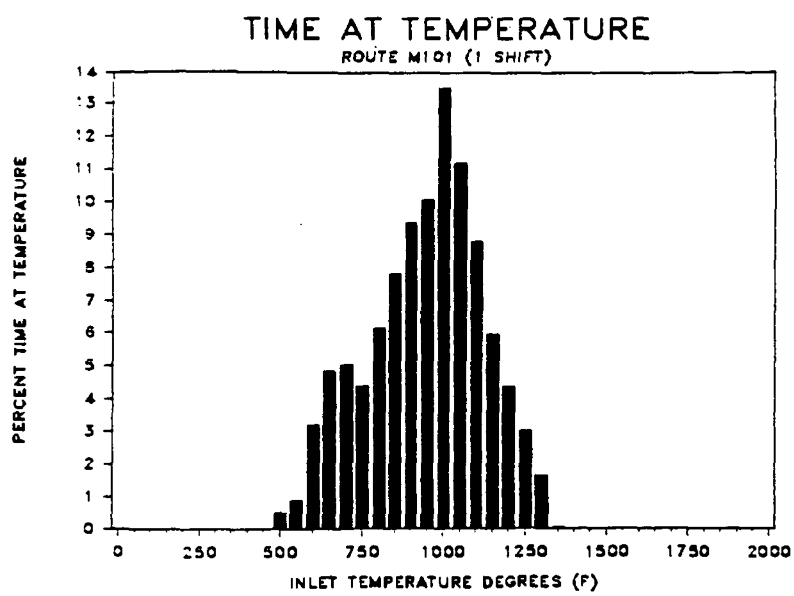
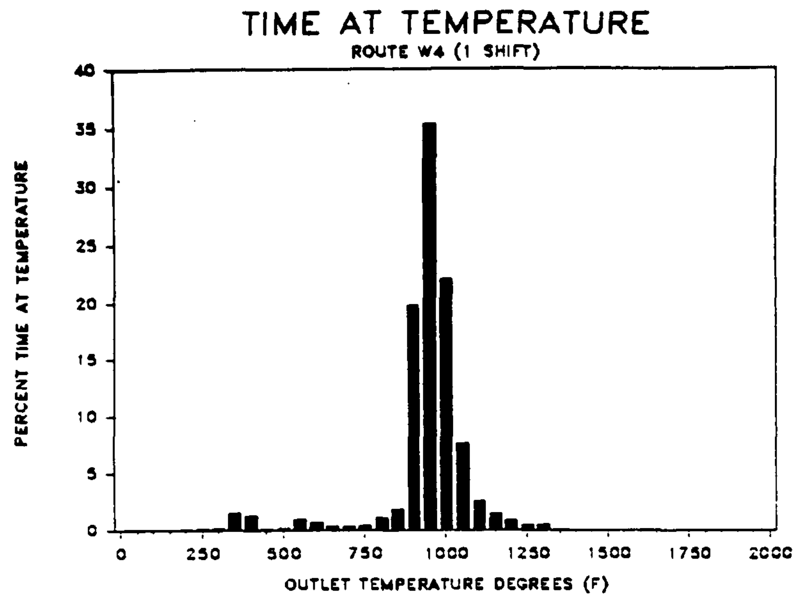
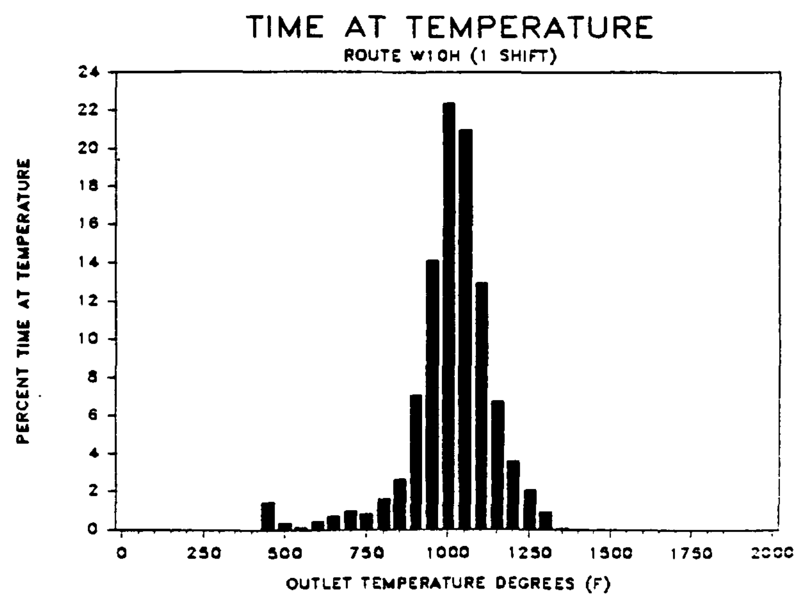
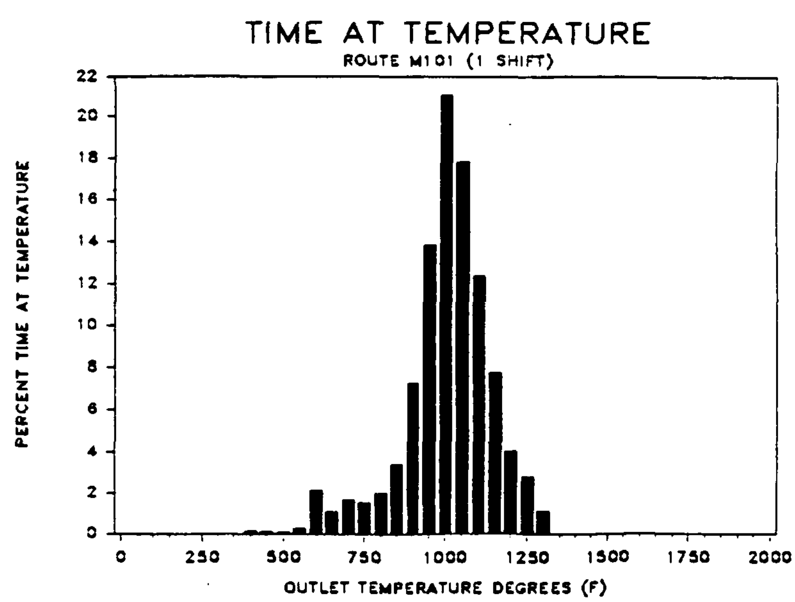


Figure 2 - Outlet Temperature Distributions of Durability Routes







The catalysts were removed from the Impalas for testing on the test vehicle at the following mileage points (plus or minus 250 miles):

4,000 miles
15,000 miles
25,000 miles

The referenced mileage intervals are miles accumulated on the catalyst, not the vehicle, and include miles accumulated on the test vehicle. Testing at the 25,000-mile point was identical to that done in Phase 2: the zero-mile testing. Testing at the 4,000- and 15,000-mile points was also identical to the testing in Phase 2, except that three converters, 1-1, 2-1, and 3-1, accumulated 25,000 miles without intermediate emissions testing. The remaining converters were removed at 4,000 and 15,000 accumulated miles for emissions testing at ATL's facilities. A breakdown by converter, vehicle, mileage and route is shown in Table 3.

V. Aged Aftermarket Versus OEM Catalyst Efficiency Results

A log book of vehicle maintenance and malfunctions was kept for both the test vehicle and the five durability vehicles. However, no vehicle was reported to have had any incidences of poor driveability or operational problems. There were also no reported incidences involving misfires or other combustion problems.

Converter 1-3 was reported as being clogged with debris prior to 15,000-mile testing. Further inspection revealed a meltdown of substrate material on the downstream end of the converter. The mileage accumulation contractor was contacted with regard to the condition of the vehicle used for the 4,000- to 15,000-mileage increment. No problems were noted on the driver's comment sheets during this period, or during a mechanic's inspection of the vehicle at the 15,000-mile point. The meltdown was unusual in that the damage was at the outlet (downstream) end of the converter. Approximately 25 percent of the honeycomb had broken away and was missing. The exposed ragged ends had melted down, but did not clog the converter. Steady-state measurements indicated backpressure was reduced. The converter was returned for the final 10,000 miles of service. No problems were experienced with subsequent converters installed on this vehicle.

Table 3

Schedule of Durability Mileage Accumulation of Aftermarket Catalytic Converters

Converter	Vehicle	Installed	Removed	Test Miles	Route
#1-1	TC-361	10-04-85	10-25-85	14,000	W-10-H
	TC-363	10-25-85	11-08-85	25,000	W-10-H
				COMPLETE	
#1-2	TC-362	09-19-85	09-28-85	4,000	M101
	TC-369	10-25-85	11-13-85	15,000	W-10-H
	TC-360	12-30-85	01-12-86	25,000	W4
				COMPLETE	
#1-3	TC-361	09-19-85	10-02-85	4,000	M101
	TC-362	10-28-85	11-13-85	15,000	W-10-H
	TC-361	12-30-85	01-20-86	25,000	W-10-H
				COMPLETE	
#2-1	TC-363	11-09-85	1-06-86	25,000	W-10-H
				COMPLETE	
#2-2	TC-362	10-16-85	10-21-85	4,000	W-10-H
	TC-369	11-13-85	12-06-85	15,000	M101
	TC-361	01-24-86	02-13-86	25,000	W4
				COMPLETE	
#2-3	TC-360	10-16-85	10-21-85	4,000	W-10-H
	TC-360	11-13-85	12-09-85	15,000	W4
	INTERNAL MATERIAL BROKE APART. TEST TERMINATED				
#3-1	TC-362	11-13-85	01-05-86	19,500	M101
	TC-363	01-07-86	01-13-86	25,000	W-10-H
				COMPLETE	
#3-2	TC-362	10-21-85	10-28-85	4,000	W-10-H
	TC-361	11-26-85	12-18-85	15,000	W-10-H
	TC-369	01-24-86	02-10-86	25,000	M101
	INTERNAL MATERIAL BROKE APART.			COMPLETE	
#3-3	TC-360	10-21-85	10-28-85	4,000	W-10-H
	TC-369	12-06-85	01-02-86	15,000	M101
	TC-363	01-24-86	02-13-86	25,000	W4
				COMPLETE	

Converter 2-3 testing was terminated prior to the 15,000-mile tests due to loss of the converter's pelleted catalyst material. Further mileage accumulation on 2-3 was canceled and the converter was returned to EPA.

Ten to twenty small fragments of bead were noted inside the inlet pipe of converter 2-2 at the 15,000-mile test point. However, this converter completed 25,000 miles of aging, though efficiency dropped substantially.

Converter 3-2 had developed a crack at the 4,000-mile test point. However, no significant deterioration in efficiency was noted through the 15,000-mile testing. Converter 3-2 fractured, however, during the final 10,000 miles of driving. A clear path was formed for exhaust gases to bypass the converter element. This represented approximately 20 percent of the surface area of the converter. All of the small pieces of substrate and liner were removed from the shell. One piece larger than the outlet of the converter remained at the 25,000-mile test point. Three tests were run on converter 3-2 at the 25,000-test point, instead of two, because the first two cycles of the modal analysis were missing from the first test.

Summaries of the aged aftermarket catalyst HC and CO conversion efficiencies compared to baseline OEM catalyst efficiencies are shown in Tables 4 and 5, respectively. A possible EPA regulatory requirement of 70 percent conversion efficiency for both HC and CO can be compared to these data. As can be seen in Tables 4 and 5, most catalysts' efficiencies are in line with the possible EPA regulatory requirement with the exceptions of the previously mentioned problem catalysts, i.e., Walker #3 after 15,000 miles, Echlin #3 after 15,000 miles, and Brown #2 after 25,000 miles. Converter 1-1 was tested a third time at 25,000 miles because it was so near the 70 percent conversion goal for HC.

Table 4

Aftermarket Catalyst HC Conversion Efficiency*

Mileage	0K		4K		15K		25K	
Test	#1	#2	#1	#2	#1	#2	#1	#2
Converter							#3	
Walker #1	87.0	85.5	--	--	--	--	66.2 69.5	70.1
Walker #2	87.9	84.5	81.6	81.5	75.9	76.3	66.5	67.0
Walker #3	83.9	82.3	76.4	74.7	36.2	36.9	29.7	27.9
Echlin #1	77.3	76.8	--	--	--	--	47.8	49.3
Echlin #2	79.4	79.5	64.2	60.7	50.5	51.7	47.9	48.4
Echlin #3	74.9	73.8	64.4	63.4	TESTING TERMINATED			
Brown #1	83.7	82.0	--	--	--	--	68.6	67.8
Brown #2	82.4	81.9	80.9	79.4	69.0	66.9	34.2 33.3	31.6
Brown #3	84.4	82.0	76.9	76.0	72.1	71.0	67.5	62.7

Mileage Summary		0K	4K	15K	25K
Walker	Avg.	85.2	78.6	56.3	54.7
	Min.	82.3	74.7	36.2	27.9
	Max.	87.9	81.6	76.3	70.1
Echlin	Avg.	77.0	63.2	51.1	48.4
	Min.	73.8	60.7	50.5	47.8
	Max.	79.5	64.4	51.7	49.3
Brown	Avg.	82.7	78.3	69.8	55.4
	Min.	81.9	76.0	66.9	31.6
	Max.	84.4	80.9	72.1	68.6

* OEM baseline HC conversion efficiency = 65.9 percent @ 83,161 miles.

Table 5

Aftermarket Catalyst CO Conversion Efficiency*

Mileage	0K		4K		15K		25K	
Test	#1	#2	#1	#2	#1	#2	#1 #3	#2
Converter								
Walker #1	96.3	95.4	--	--	--	--	87.9 89.8	88.5
Walker #2	97.3	94.5	95.2	96.7	93.4	94.1	90.1	89.6
Walker #3	96.4	93.4	94.1	92.0	48.1	50.6	37.2	35.0
Echlin #1	87.9	89.9	--	--	--	--	56.7	58.3
Echlin #2	91.3	92.0	78.7	74.5	61.8	62.7	58.0	56.9
Echlin #3	88.6	86.4	76.9	78.2	TESTING TERMINATED			
Brown #1	94.8	92.5	--	--	--	--	85.1	85.2
Brown #2	93.0	93.6	94.1	92.2	86.2	84.0	30.2 31.9	30.9
Brown #3	95.8	93.5	90.7	90.1	86.3	86.3	81.4	79.4

Mileage Summary		0K	4K	15K	25K
Walker	Avg.	95.6	94.5	71.6	71.6
	Min.	93.4	92.0	48.1	35.0
	Max.	97.3	96.7	94.1	90.1
Echlin	Avg.	89.4	77.1	62.2	57.5
	Min.	86.4	74.5	61.8	56.7
	Max.	92.0	78.7	62.7	58.3
Brown	Avg.	93.9	91.8	85.7	65.5
	Min.	92.5	90.1	84.0	30.2
	Max.	95.8	94.1	86.3	85.2

* OEM baseline CO conversion efficiency = 79.0 percent @ 83,161 miles.