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Evaluation of Methods to Determine Catalyst Efficiency in the Inspection / Maintenance Process

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ABSTRACT

Two new, low cost methods used to identify inefficient or damaged catalytic converters were evaluated on in-use vehicles. The first technique was a non-intrusive propane injection catalyst test procedure developed by General Motors as part of their overall diagnostic strategy. The second technique utilized an Olympus fiber-optic borescope to visually assess the condition of catalytic converter substrates. Results from the two new techniques were compared against those from standard modal catalyst testing and IM240 tailpipe emission testing.

The test results from seventy vehicles show the propane injection test to be generally effective at discriminating between converters with high and low conversion efficiencies. The fiber-optic borescope was less successful in identification of inefficient catalysts. This is because some catalyst failures are not readily identifiable while others have identifiable problems, but continue to perform at reasonable efficiencies.

INTRODUCTION

The catalytic converter is a critical component of the emission control system on most vehicles. It is typically responsible for oxidizing more than 70 percent of the engine-out hydrocarbons and more than 50 percent of the engine-out carbon monoxide. Current technology three-way catalytic converters also reduce engine-out oxides of nitrogen (NOx). More effective catalysts and lower engine-out emissions have enabled automotive emission system designers to meet increasingly difficult new vehicle tailpipe emission standards.

Catalysts are capable of lasting the life of the vehicle. Thermal degradation, poisoning, or rough treatment can prevent this. Thermal degradation can occur when significant quantities of unburned fuel are allowed to react in the catalyst. This may occur if a vehicle's closed-loop control system malfunctions or if persistent misfire occurs. Catalytic efficiency can also be reduced substantially by poisoning with lead or sulfur compounds. This was a relatively common occurrence when leaded fuel was generally available at a discount to unleaded fuel. Catalysts can also be physically damaged by accidental rough treatment or deliberate tampering.

Motorists are usually unaware of catalyst problems unless they affect vehicle performance. A melted substrate, for example, may excessively restrict exhaust flow and affect driveability.

Traditional basic I/M (idle) tests rarely require catalyst replacement to achieve program cutpoints. Anti-tampering programs (ATP) usually required catalyst replacement only if they were missing or had been clearly misfueled.

Until recently, procedures to easily and accurately evaluate catalyst condition had not been developed. The only reliable, moderate cost method of evaluating converter condition was to remove the catalyst from the exhaust system to permit visual inspection of the converter bed. Less reliable methods included tapping on the converter to check if it sounded hollow or shaking it to determine if it rattled. As a result of the lack of demand and the difficulty in diagnosis, relatively few catalyst replacements were performed.

Enhanced IM240 programs were specifically designed to identify vehicles whose emissions remained low during simple idle or steady state I/M tests, but which were high emitters under real world transient operating conditions. It is expected that a substantial number of vehicles will require catalyst replacement in order to achieve passing scores on the enhanced I/M test. The new enhanced test also evaluates NOx emissions. This may potentially increase the number of vehicles requiring catalyst replacement.

Methods for assessing catalytic converters have improved. The subject of this study is an evaluation of two of the new methods. The first is a non-intrusive test developed by General Motors (GM). The GM test uses a propane injection technique and a standard garage grade emissions analyzer to evaluate the ability of an installed catalytic converter to oxidize hydrocarbons. The second is a borescope method developed by Olympus of America. The borescope is a fiber-optic device which can be inserted in an oxygen sensor hole or other opening and maneuvered through the exhaust system to the catalyst. It enables the technician to visually evaluate the condition of the catalyst substrate.

PROGRAM DESCRIPTION

A sample of low, medium, and high emitting vehicles was procured from an I/M lane. Vehicle catalyst condition was evaluated three ways. The GM catalyst efficiency test was performed using GM service manual procedures, a borescope was used to visually inspect the catalyst, and catalyst efficiency was measured using continuous modal exhaust samples collected before and after the catalytic converter. The vehicles were inspected to determine the cause(s) of high emissions. Repairs and retests were performed on a limited number of vehicles.

Vehicle Recruitment - A total of seventy in-use, 1983 and later model year vehicles were recruited from State of Arizona I/M lanes. Arizona uses the IM240 test in their state emission inspection program. Arizona's I/M lanes are programmed to reduce total test time by early termination of the 240 second test when very clean and very dirty vehicles are encountered (fast pass/fast fail procedures). One lane, operated under EPA sponsorship, was programmed to require completion of the 240 second schedule on all vehicles.

Cutpoints were selected to categorize incoming vehicles as low, medium, and high emitters. Special cutpoints were developed to identify low emitters from the fast pass/fast fail lanes. Both the full 240 second and fast pass/fast fail cutpoints are displayed in Table 1. Vehicles with both HC and CO scores below the "low" cutpoints were classified as low emitters. Vehicles with either HC or CO higher than the cutpoints were considered to be mid and high emitters.

Most vehicles arriving at the I/M lane were low emitters. Relatively few converter failures were expected from such vehicles. Extremely high emitters were expected to include a high proportion of catastrophic converter failures. Preference was given to mid range emitters for this program in an attempt to procure a substantial sample of moderately deteriorated catalysts. However, the final sample included more high emitters than the original recruitment targets since the number of vehicles falling exactly between the low and high cutpoints was limited.

TABLE 1

IM240 Recruitment Cutpoints

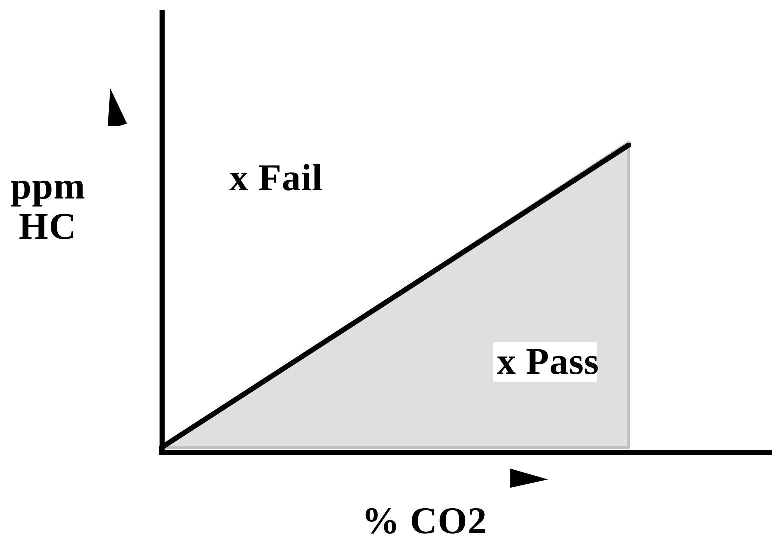
Emission Class	**Test Duration**	**HC (g/mile)**	**CO (g/mile)**	**Number of Vehicles**
Low	Fast Pass	< 0.4	< 7.5	15
	Full Test	< 0.8	< 15.0	
Medium	Both	between	between	23
High	Both	> 1.2	> 30.0	32

GM Catalyst Test Procedure - In response to the increased demands of the new enhanced I/M tests, General Motors has developed improved diagnostic procedures for vehicles failing such inspections. These procedures include a newly developed method for evaluating the state of a catalytic converter without removing it from a vehicle. The new procedures were developed and documented by the GM Service Technology Group, Powertrain Control Service Engineering, and published in General Motors new Inspection / Maintenance repair manual[1].

The procedure developed by GM involves the introduction of a calibrated amount of propane or other similar hydrocarbon to a preheated catalyst. The converter is heated by running the engine at 2500 rpm high idle for a few minutes. The engine fuel delivery and spark systems are then disabled, and propane is introduced into the engine while it is being turned over with the starter motor. Exhaust gas levels are monitored to determine the amount of unconverted hydrocarbons and converted carbon dioxide (CO2) at the vehicle tailpipe. The volume of hydrocarbons introduced into the engine are carefully metered to insure that enough hydrocarbons are available to challenge the vehicle converter. The ratio of CO_2 to unburned hydrocarbons is used to determine converter efficiency.

A series of procedures based on the specific vehicle fuel control system, engine size, and converter configurations are provided in the GM manual. These include procedures for single and dual catalyst configurations and carbureted, throttle body, and port fuel injection systems. A chart is provided in the GM manual for several configurations which indicates the appropriate flow of propane based on engine size. A generalized chart showing pass/fail regions is shown in Figure 1. The typical slope of the line in the charts is approximately 300 ppm HC per 1% CO2.

FIGURE 1
GM Test Pass/Fail Chart



Higher CO2 / lower HC is desirable

The GM procedures were successfully applied to a wide variety of foreign and domestically produced vehicles, both GM and non-GM. The only discrepancy noted was with an early program vehicle which displayed a failing GM test score but which clearly passed the IM240 and other tests. It was found that the converter warm up procedure must be rigorously observed, as repeated tests with the vehicle resulted in reproducible pass/fail reversals caused by insufficient catalyst preheating. It was later discovered that GM had extended the warm up period in their manual. All warm-ups after the third vehicle in the program were performed with a stop watch to insure compliance with warm-up specifications.

Borescope Inspection Procedure - The fiber optic based borescope permits visual inspection of areas not normally accessible without disassembly or cutting away of obstructing components. The borescope allows the user to visually inspect the inside of an exhaust and catalyst system and see the catalyst substrate from several views without requiring disassembly of the exhaust system. Borescope products are commonly used in a wide variety of applications, including manufacturing and inspection, and medical examinations. They have not previously been used specifically to inspect catalytic converters suspected of causing or contributing to IM240 failures.

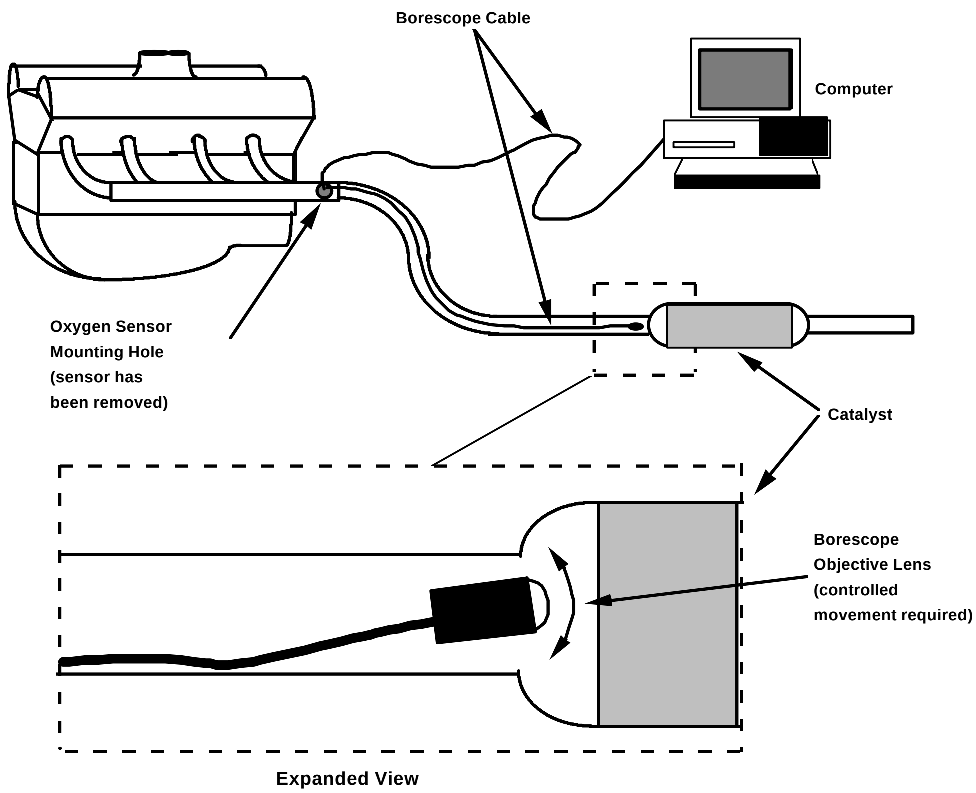
A commercial borescope and the necessary support equipment was obtained from Olympus of America under an EPA cooperative research and development agreement (CRADA). The equipment package consisted of the borescope fiber-optics, a camera, a computer, the necessary adapters, and imaging software. The borescope was of sufficient length to reach catalysts mounted at some distance from the engine. It was also of sufficiently small diameter to fit through an oxygen sensor port.

The borescope was used to examine the catalyst of vehicles 60 through 125 in this program (see Table A1). Digital pictures of the most interesting view(s) of the substrate were captured. Cracked, missing, and melted down converters were classified as "failing" the borescope test. Many of the converters showed no visible defects. Several displayed minor defects, three could not be conclusively scored as passing or failing.

Figure 2 depicts the use of the borescope to enter the vehicle's exhaust system to view the catalyst surface.

FIGURE 2

Borescope Used to View Automotive Catalyst



the operating vehicle. A parallel sample was withdrawn downstream of the converter. Mass emissions were then computed before and after the converter on a second by second basis. Calculation procedures conformed to those described in SAE Surface Vehicle Information Report J1094[2]. Pre and post converter mass emissions were used to compute converter efficiency.

Catalyst Efficiency Test - The catalyst condition of the randomly procured vehicles was not known. While it can be safely assumed that the converter of a low emitting vehicle is fully functional, a number of factors other than converter efficiency can lead to high emitting vehicles. Some method of isolating catalyst condition from other operating variables was required to evaluate the GM and borescope procedures being studied.

The ideal method for measuring converter efficiency requires removal of the converter from the vehicle and flowing well characterized feed gases at controlled temperatures through the converter on a test bench. As resource limitations for this program precluded the use of the bench test procedure, an alternative method was employed.

A continuous sample of undiluted exhaust was withdrawn from ahead of the catalytic converter of

These procedures are very familiar to emission system development engineers. While reliable for evaluating converter efficiency on vehicles which have proper fuel / air mixture control, the procedures on occasion yielded unexpected results on the in-use vehicles studied in this program. This is because proper operation of a catalytic converter is dependent on feed gas properties, oxygen levels, and temperatures. In this study, a number of the vehicles which were tested did not have proper air/fuel control. If insufficient oxygen is present in the exhaust stream, a converter will not be chemically able to oxidize excess hydrocarbons and carbon monoxide. The modal efficiency test would result in a low score, even if the converter was capable of much higher conversion efficiencies.

It was decided after program startup that low cost emission control system repairs would be performed, if necessary, and repeat modal catalyst efficiency tests and GM catalyst tests would be done subsequent to these repairs. This was required to achieve an accurate assessment of converter condition. Seven vehicles were repaired during the study, and five more would have been done if program resources had been available. The typical repair that was done focused on the oxygen sensor, and other critical closed-loop control systems components. Major internal engine repairs (i.e., valve jobs, piston ring replacement, etc.) were not performed.

TABLE 2
GM / IM240 Modal Efficiency Comparison

Modal HC % Efficiency	GM Efficiency Test	
	Pass	**Fail**
Pass (³75%)	41	4
Fail (<75%)	6	19

RESULTS

The purpose of this study was to evaluate two relatively new approaches for evaluating in-use vehicle catalytic converters that do not require disassembly of a vehicle's exhaust system. The first method was a procedure developed by General Motors (GM) to measure hydrocarbon conversion efficiency. The second method was a borescope used to visually inspect the catalyst substrate. Continuous modal emissions before and after the converter during an IM240 were measured. The vehicle emission control systems, particularly oxygen sensor and fuel control signals, were also evaluated by repair technicians. Table A1 in the Appendix summarizes the results of these steps.

Table A1 includes a vehicle number and a brief description of each test vehicle. The results of the repair technician's inspection is listed under "O2 Sens" column for an evaluation the vehicle's oxygen sensor, and "CL Sys" column for the repair technician's overall evaluation of the vehicle's closed loop fuel feedback system. Scores are Pass/Fail/Marginal as indicated by a table entry of P, F, or ?. Some vehicles were repaired, and these are indicated by a "Yes" under the "Veh Repair" column heading. Note that the closed loop function of each of the repaired vehicles was in control, but a number of other vehicles were not repaired for this program. Two consecutive repeats of the General Motors test were performed, as tabulated under the headings "GM1" for the first test and "GM2" for the second. The column headed GM1/GM2 is marked with a "•" when the two tests did not agree. Next are the gram/mile HC scores before and after the catalytic converter, with a computed converter efficiency and a Pass/Fail rating based on a 75% cutpoint. The GM1/HC% column is flagged with a "•" when the modal efficiency test does not agree with the first GM test. The last three columns reflect the Pass/Fail/Marginal scores obtained with the borescope visual inspection. Marginal scores are indicated with a question mark. Pass/Fail ratings that disagree with the first GM test and the modal efficiency test are again marked with a "•" under the headings "vs GM" and "vs %".

General Motors Catalyst Test - The GM test has clearly defined Pass/Fail limits. The modal efficiency test, particularly during the new IM240 test, does not. However, examination of the data indicated that a HC modal efficiency less than 70 to 80 percent was a good predictor of an IM240 failure. As a result, a cutpoint of 75 percent was selected for comparison with the GM pass/fail criteria. Test results for the final test (after repair) of each vehicle were tabulated with respect to IM240 HC modal efficiency (pass/fail) and GM converter efficiency test (pass/fail). This tabulation is summarized in Table 2.

These results are positive, indicating good agreement between the two methods. Note that the majority (86 percent) of the vehicles in this program either pass both the GM test and converter efficiency test or fail both tests. Of concern, however, were the four vehicles which failed the GM test but passed the converter efficiency test, and the six vehicles which passed the GM test, but which displayed low efficiency. These ten vehicles were more carefully investigated.

The more serious problem with a short test of this type is the incorrect identification of passing components or vehicles (False Failure). This type of error results in unnecessary costs and repairs. The GM test results on vehicles 73, 89, 91, and 98 could be considered false failures, and therefore were examined carefully.

Vehicles 89, 91, and 98 each displayed relatively low IM240 emissions. Since they passed the IM240 tailpipe test, it is unlikely that these vehicles would be subjected to an emissions diagnostic procedure. In addition, the modal efficiencies of these four vehicles were between 80 and 83 percent, only slightly above the 75 percent cutpoint used.

The discrepancy on the remaining vehicle, #73, could not be explained. However, it is not likely due to unfamiliarity with the test procedure, since this vehicle was the eighteenth vehicle tested, and the technicians understood the procedure quite well by that time. The vehicle did display a relatively high engine out score (5.60 g/mi HC), which may have inflated the HC modal efficiency (80%). Further study would be required to conclusively determine the cause of this discrepancy.

If a short test fails to identify a defective component (False Pass), motorists will not be penalized with unnecessary repair costs, but the emission reduction benefits from the program will be diminished. Vehicles 71, 78, 119, 120, 121, and 124 potentially fell into this category. Each easily passed the GM short test, but clearly failed to achieve the modal efficiency cutpoint of 75%, and failed the IM240 test.

Each of the "False Pass" vehicles except #124 failed a repair technician's inspection of the closed loop fuel control system. Catalytic converters require the controlled fuel / air mixture provided by the feedback system to operate efficiently. The GM test, by design, isolates the test converter from the fuel control system. From an engineering basis, repairs to the oxygen sensor or other closed-loop control system components should substantially increase the measured modal efficiency test results. In order to operate properly, catalysts require the constant fuel/air mixture oscillations that a closed-loop system provides.

Test results from the seven repaired vehicles demonstrate considerable improvement in measured catalyst efficiency, even though no changes to the catalyst itself were made. The seven vehicles which were repaired are listed in Table 3. Each vehicle was initially determined not to be in closed-loop operation. The measured HC efficiency increased on all but one vehicle following repairs. The average increase in measured converter efficiency was 33%. Of the vehicles which passed the GM catalyst test, the average increase was 51%. The oxygen sensor was replaced on all but one of the seven vehicles. Fuel injectors were replaced on two vehicles. Some diagnosed problems were not repaired, including EGR system repairs and internal engine repairs.

The results of the GM test and the converter efficiency test were contradictory on four of the seven vehicles before repair. All of the vehicles were in agreement following repairs. While it is recognized that some of the after repair scores were marginal, with "passing" scores of 75 and 76, and "failing" scores of 71 and 72.8, the overall trend follows expected results. It is not clear why the results of the GM test on vehicle 111 changed from Fail to Pass. It is apparent that closed loop operation must be restored before a catalyst change is considered.

Vehicle 124 passed the closed loop operation test and the GM test, but failed the modal efficiency test and the IM240. No specific cause for this difference was found.

Borescope Catalyst Test - The Olympus Borescope (Borescope) was used to visually inspect the interior of 64 catalytic converter containers, and to observe the condition of the catalyst substrates or catalyst pellets. Images of the catalyst substrates were captured electronically and saved in a digital format. Printing was performed using a standard laser printer.

The operational performance of the borescope was excellent. The instrument worked as described and did not need repairs or replacement parts. The technicians using the device reported that the instrument was easy to use and to maneuver into position. The fiber optics were long enough to reach the catalyst, and small enough to fit through the oxygen sensor hole. The pictures were clear, and could easily be magnified if desired. Some resolution of the image was lost in the digitization and printing process. This would not be relevant to the field repair technician.

Borescope results were less clear than the GM test and IM240 scores. Very few of the converters displayed clear failures, including several of the vehicles with poor GM and IM240 converter efficiencies. Three categories were used to classify borescope readings, "PASS", "FAIL" and "MARGINAL". The "PASS" results are from vehicles whose catalyst substrates appeared to be structurally intact and showed no obvious signs of thermal or physical damage. The "FAIL" group includes catalysts with missing, fragmented, or badly melted substrates. All of the catalysts classified as "FAIL" showed significant damage and defects that would be readily apparent to untrained observers. The "MARGINAL" group included catalysts with substrates which may be melted in a few small spots, or which could not be clearly categorized as "PASS" or "FAIL". Table 4 summarizes the results of the borescope test. The GM test was used as the baseline for rating the borescope because of the shortcomings of the modal test previously described (see section Catalyst Efficiency Test).

TABLE 3
Modal Catalyst Efficiencies of Repaired Vehicles

	Modal HC Efficiency (%)			GM Catalyst Test	
Vehicle Number	Before Repair	After Repair	Change	Before Repair	After Repair
81	16.6	76.0	59.4	Pass	Pass
90	51.6	82.3	30.7	Pass	Pass
106	61.5	71.0	9.5	Fail	Fail
110	29.6	50.8	21.2	Fail	Fail
111	53.8	92.2	38.4	Fail	Pass
113	79.0	72.8	-6.2	Fail	Fail
118	0.0	75.0	75.0	Pass	Pass
ALL	41.7	74.3	32.6		
Passing GM Test	30.5	81.4	50.9		

A much lower number of catalysts were unequivocally identified as "FAIL" with the borescope than with either the GM test or the modal efficiency test. For example, only four of the nineteen converters that failed the GM test were positively identified as failures with the borescope. The remaining fifteen vehicles could not be positively identified. This result suggests a significant percentage of the deactivated, in-use catalysts may not suffer a visual failure which is catastrophic enough to be identified by a technician using a borescope.

TABLE 4
Borescope versus GM Test

Borescope	**GM Efficiency Test**	
	Pass	**Fail**
PASS	39	13
MARGINAL	1	2
FAIL	5	4

It is interesting to note that five converters failed the visual inspection but passed the GM test. Three of these were cracked with large sections missing and one appeared melted and should have caused high back pressure. Only one was a very high emitter on the IM240.

The first of the three catalysts is from vehicle #87. This catalyst's substrate was examined, and found to be half melted. It was not completely clear if the damage was limited to the surface of the substrate or if it went further into the substrate. This catalyst passed the GM test, and had a catalytic converter efficiency of about 95 percent. Vehicle #70 was likewise found to be damaged. In this case, a large portion of the substrate was missing. This vehicle passed both GM catalyst tests, and had an HC efficiency of 89%. The catalyst substrate on vehicle #95 also has a piece missing. It had variable results on the GM test - passing the test the first time but failing on a retest. The modal HC catalyst efficiency was measured at 84%. Because each of the vehicles received passing IM240 scores, they probably would not have been considered candidates for converter replacement. However, visually all three appear to be damaged, and may completely fail before their next scheduled I/M test.

The borescope is a subjective tool which requires interpretation by the inspector. Obvious cases where the substrate is badly cracked, fragmented, melted or missing are easy to determine. Arguably, most of these should be replaced, and the underlying cause of the problem corrected, even if the measured catalytic activity is still fairly high. Failure to correct the underlying problem and replace the catalyst could lead to an almost complete loss of the emission control system, and possibly vehicle performance problems due to exhaust flow restriction.

Unfortunately, many of the catalysts in the "PASS" and "MARGINAL" group had borescope pictures which were not completely conclusive as to the state of the substrate. Some had small areas which appeared "dark" on the picture or appeared to be melted in a small area. None of these cases seemed to be major problems that clearly required action.

CONCLUSIONS

1. The GM Catalyst efficiency test was demonstrated to efficiently discriminate between converters with high and low conversion efficiencies. A structured diagnostic approach is mandatory to use the GM test. The fuel management system must

be in proper closed-loop operation before the converter evaluation test can be performed.

2. The borescope was less successful in identification of improperly performing catalysts. Some converter failure modes were not readily identifiable, while other minor failures did not appear to affect converter effectiveness. The borescope did identify some converters that passed all tests, but which would probably fail in the near term.

ACKNOWLEDGMENTS

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2. "Constant Volume Sampler System for Exhaust Emissions Measurement", SAE Surface Vehicle Information Report J1094, revised June, 1992.

TABLE A-1

					Veh	O2	CL			GM1	HC		HC Efficiency		GM1	Boroscope		
Veh	Yr	Make	Disp	Fuel	Repair	Sens	Sys	GM1	GM2	GM2	Pre	Post	[3]%	P/F	HC%	Rating	vs GM	vs %
51	87	Plym	2.2	PFI		F	F	F	F		-	8.30[33]	-	F		-		
52	87	Niss	2.0	PFI		F	F	F	F		2.50[33]	0.70[33]	72	F		-		
53	87	Chev	2.0	PFI		P	P	P	P		2.20[33]	0.50[33]	77	P		-		
54	84	Niss	2.6	PFI		F	F	F	F		2.70[33]	1.90[33]	30	F		-		
56	84	Niss	2.0	PFI		F	F	F	F		4.10[33]	2.70[33]	34	F		-		
60	93	Chev	2.2	PFI		P	P	P	P		2.20[33]	0.13[33]	94	P		P		
62	89	Chev	2.8	PFI		P	P	P	P		3.00[33]	0.22[33]	93	P		P		
63	86	Pont	2.8	PFI		F	F	F	F		4.60[33]	1.82[33]	60	F		F		
64	91	Mits	1.5	PFI		P	P	P	P		2.30[33]	0.11[33]	95	P		P		
65	89	VW	1.8	PFI		F	F	F	F		2.40[33]	0.84[33]	65	F		P	•	•
66	90	Ford	3.0	PFI		P	P	F	F		2.70[33]	1.23[33]	54	F		P	•	•
67	86	Ford	2.3	TBI		P	P	P	P		4.00[33]	0.30[33]	93	P		P		
68	87	Buick	2.0	TBI		P	P	F	P	•	1.90[33]	0.49[33]	74	F		P	•	•
69	92	Chev	3.1	PFI		F	F	P	P		2.60[33]	0.28[33]	89	P		P		
70	88	Chev	2.8	PFI		F	F	P	P		3.20[33]	0.35[33]	89	P		F	•	•
71	87	Ford	1.9	TBI		F	F	P	P		-	10.64[33]	-	F	•	F	•	
72	91	Geo	1.6	PFI		P	P	P	P		6.40[33]	0.74[33]	88	P		P		
73	83	Chev	2.0	TBI		F	F	F	F		5.60[33]	1.10[33]	80	P	•	P	•	
74	84	VW	1.8	PFI		P	F	F	F		2.60[33]	0.70[33]	73	F		P	•	•
75	84	Pont	2.5	TBI		P	P	P	P		1.80[33]	0.35[33]	81	P		P		
76	89	Olds	2.8	PFI		P	P	P	P		3.30[33]	0.82[33]	75	P		P		
77	88	Olds	3.8	PFI		F	F	P	P		2.19[33]	0.24[33]	89	P		P		
78	89	Niss	1.6	TBI		P	F	P	P		4.98[33]	2.13[33]	57	F	•	P		•
79	83	Cadi	4.1	TBI		F	F	F	F		2.99[33]	1.01[33]	66	F		P	•	•
80	92	Chev	3.1	PFI		P	P	P	P		4.08[33]	0.11[33]	97	P		P		
81	85	Chry	2.2	TBI	Yes	P	P	P	P		2.45[33]	0.59[33]	76	P		P		
82	93	Toyo	1.5	PFI		P	P	P	P		2.24[33]	0.26[33]	88	P		P		
83	90	Mazda	1.8	PFI		P	P	P	P		1.74[33]	0.10[33]	94	P		P		
84	91	Chry	2.5	TBI		P	P	P	P		1.15[33]	0.05[33]	96	P		P		
85	86	Dodge	2.2	TBI		P	P	P	P		3.82[33]	0.73[33]	81	P		P		
86	87	Pont	3.8	PFI		P	P	P	P		2.47[33]	0.07[33]	97	P		-		
87	93	Niss	1.6	PFI		P	P	P	P		2.20[33]	0.11[33]	95	P		F	•	•
88	88	Mazda	3.0	PFI		P	P	P	P		3.46[33]	0.58[33]	83	P		P		
89	90	Geo	1.6	TBI		P	P	F	F		1.84[33]	0.34[33]	82	P	•	P	•	
90	90	Dodge	2.5	TBI	Yes	P	P	P	P		1.81[33]	0.32[33]	82	P		F	•	•

TABLE A-1

					Veh	O2	CL			GM1	HC		HC Efficiency		GM1	Boroscope		
Veh	Yr	Make	Disp	Fuel	Repair	Sens	Sys	GM1	GM2	GM2	Pre	Post	^{3}%	P/F	HC%	Rating	vs GM	vs %
91	86	Buick	3.8	PFI		?	P	F	F		3.44^{33}	0.68^{33}	80	P	•	P	•	
92	86	Ford	2.3	TBI		?	F	F	F		4.86^{33}	1.69^{33}	65	F		P	•	•
93	91	Chev	3.1	PFI		P	P	P	P		2.39^{33}	0.34^{33}	86	P		P		
94	88	Niss	1.6	TBI		P	P	P	P		2.48^{33}	0.31^{33}	88	P		P		
95	87	Olds	3.8	PFI		P	P	P	F	•	2.15^{33}	0.35^{33}	84	P		F	•	•
96	91	Chev	3.1	PFI		P	P	P	P		2.61^{33}	0.07^{33}	97	P		P		
97	88	Dodge	2.2	TBI		P	P	P	P		3.58^{33}	0.40^{33}	89	P		P		
98	83	Niss	2.8	PFI		F	F	F	F		2.58^{33}	0.45^{33}	83	P	•	P	•	
99	92	Honda	2.2	PFI		P	P	P	P		1.72^{33}	0.09^{33}	95	P		P		
100	88	Mazda	2.2	PFI		P	P	P	P		1.63^{33}	0.16^{33}	90	P		P		
101	90	Ford	1.9	TBI		P	P	P	P		1.91^{33}	0.24^{33}	87	P		P		
102	87	Toyo	2.8	PFI		P	P	P	P		3.26^{33}	0.19^{33}	94	P		P		
103	88	Honda	2.0	PFI		P	P	P	P		1.84^{33}	0.21^{33}	89	P		P		
104	88	Toyo	1.6	PFI		P	P	F	F		1.70^{33}	0.48^{33}	72	F		P	•	•
105	87	Niss	2.0	PFI		P	P	P	P		2.66^{33}	0.31^{33}	88	P		P		
106	85	Niss	2.0	PFI	Yes	P	P	F	F		2.94^{33}	0.86^{33}	71	F		F		
107	85	Niss	2.0	PFI		F	F	F	F		-	9.06^{33}	-	F		F		
108	90	Niss	1.6	TBI		P	P	P	P		2.39^{33}	0.56^{33}	77	P		P		
109	85	Pont	2.5	TBI		F	F	F	F		4.07^{33}	1.85^{33}	55	F		?		
110	83	Cadi	4.1	TBI	Yes	P	P	F	F		4.65^{33}	2.29^{33}	51	F		?		
111	87	Niss	1.6	PFI	Yes	P	P	P	P		2.69^{33}	0.21^{33}	92	P		P		
112	90	Chev	3.1	PFI		F	F	P	P		3.99^{33}	0.78^{33}	80	P		P		
113	92	Toyo	1.5	PFI	Yes	P	P	F	F		7.06^{33}	1.92^{33}	73	F		P	•	•
114	91	Cadi	5.0	TBI		F	F	P	P		2.60^{33}	0.33^{33}	87	P		P		
115	84	VW	1.7	PFI		F	F	F	F		4.84^{33}	3.22^{33}	33	F		F		
116	88	Chry	2.2	PFI		P	P	P	P		1.78^{33}	0.29^{33}	84	P		P		
117	86	Cadi	4.1	TBI		F	F	P	P		2.31^{33}	0.48^{33}	79	P		P		
118	86	Pont	1.8	TBI	Yes	P	P	P	P		2.10^{33}	0.53^{33}	75	P		?		
119	88	Chev	2.8	PFI		F	F	P	P		3.48^{33}	1.27^{33}	64	F	•	P		•
120	86	Olds	3.8	PFI		F	F	P	P		3.69^{33}	1.86^{33}	50	F	•	P		•
121	90	Chry	3.0	PFI		F	F	P	P		2.62^{33}	1.29^{33}	51	F	•	P		•
122	86	Buick	3.8	PFI		F	F	P	P		3.90^{33}	0.12^{33}	97	P		P		
123	87	Ford	5.0	PFI		P	P	F	F		2.08^{33}	1.16^{33}	44	F		P	•	•
124	88	Mazda	3.0	PFI		P	P	P	P		2.70^{33}	1.23^{33}	54	F	•	P		•
125	86	Chry	2.5	TBI		F	F	P	P		2.55^{33}	0.34^{33}	87	P		P		