

CATALYTIC CONVERTER TESTS

1. CRANKING TEST

There is typically little (390 to 400 PPM at sea level) CO₂ present in the atmosphere. CO₂ is a product of combustion. Therefore any carbon dioxide emissions measured during typical starter draw test, with ignition disabled must be created in the catalytic converter.

A good catalytic converter should be capable of converting the Hydrocarbon fuel (HC) that is pumped through the engine during the starter test to 12% carbon dioxide.

In order to create 12% CO₂ during a starter draw test the following must occur:

1. The catalytic converter must be completely warmed up.
2. Fuel delivery must be functioning normally. The CO₂ is being created by converting the fuel that is being pumped through the engine.
3. Ignition must be completely disabled.

THE TEST:

1. Start the engine and drive the car to insure that it is warmed up completely.
2. Run the engine at 2000 rpm to insure that the catalytic converter is hot.
4. Turn off the ignition or hit the analyzer kill switch.
5. IMMEDIATELY after the engine stops, disable the ignition (ground the coil secondary or disconnect the coil primary) and crank the engine over while watching the CO₂ levels on the exhaust analyzer.

NOTE:

**THE FUEL SYSTEM MUST REMAIN FUNCTIONAL! DO NOT DISABLE RPM SENSOR OR ENGAGE CLEAR FLOOD MODE!
KILL THE IGNITION SYSTEM ONLY!
DO NOT ALLOW THE CONVERTER TO COOL DOWN**

4. The CO₂ level should reach and maintain 12% in about 10 seconds. If the CO₂ level does not reach at least 12%, or the CO₂ level only spikes to 12%, the catalytic converter is weak.

If the CO₂ level is below 12% make sure that there is sufficient HC and O₂ to make the CO₂ from. If the CO₂ level drops below 1% or HC drops below 500 ppm the test will not be valid.

THIS TEST IS DIFFICULT TO PERFORM ON MANY DIS CARS SINCE THE IGNITION IS NOT EASILY DISABLED WITHOUT DISABLING IGNITION. USE THE SNAP THROTTLE TEST ON SUCH CARS

2. SNAP THROTTLE TEST

When the engine is running at a stoichiometric 14.7:1 fuel mixture with no air injection there is very little oxygen in the exhaust. Cars equipped with Carburetors will have higher normal levels of oxygen due to poorer fuel atomization and vaporization.

During a snap throttle test" CO will increase due to a suddenly rich mixture on acceleration. CO will continue to increase until the O₂ level begins to rise. During this snap acceleration all excess oxygen will be used up by the catalytic converter to convert CO to CO₂. As the O₂ level rises O₂ will be used up by the 'CAT" to convert CO to CO₂ and the CO level will begin to drop as O₂ rises. A good "CAT" will therefore prevent the O₂ level from exceeding 1.2% until the CO level begins to drop.

THE TEST:

1. Drive the car until the engine and catalytic converter are fully warmed up.
2. Disable the air injection system.
3. Run the engine at 2000 rpm and wait for stable exhaust readings with Oxygen level no higher than 0.5%. Propane enrichment may be used to reduce oxygen level to 0.5%.
4. Snap and release the throttle.
5. Watch the **CO** emissions climb and note the Oxygen level at the instant the CO level peaks. Oxygen level at the instant that Co level peaks should not exceed 1.2%.

Note: It is normal for Oxygen level to rise after CO has peaked.

If the O₂ level exceeds 1.2% before the CO level peaks the catalytic converter is weak.

This test works best on cars that have sequential fuel injection and DIS. The cranking CAT test tends to be difficult to perform on these same cars

3. INVASIVE TESTING

The CAT efficiency can be determined by sampling the exhaust gas before and after the CAT. Kits are available from Thexton (No. 389), OTC and others to tap through single wall exhaust pipes. Other pre-CAT sampling locations may include the EGR port, EGO port and air injection ports. (EGO is not recommended). Record both the before cat and tailpipe exhaust gas with the engine well tuned, preconditioned, no exhaust leaks and no air injection. Fuel mixture may have to be manipulated and/or misfires induced to create the proper oxygen level for proper evaluation.

$$\frac{(\text{HC in}) - (\text{HC out})}{(\text{HC in})} \times 100 = \text{CAT HC efficiency}$$

$$\frac{(\text{CO in}) - (\text{CO out})}{(\text{CO in})} \times 100 = \text{CAT CO efficiency}$$

$$\frac{(\text{NOx in}) - (\text{NOx out})}{(\text{NOx in})} \times 100 = \text{CAT NOx efficiency}$$

HC oxidation efficiency should be 90% when O₂ in exceeds 1% and O₂ out exceeds 0.5%. You may need to induce a misfire to create the proper O₂ levels.

CO oxidation efficiency should be 90% when O₂ in exceeds 1% and O₂ out exceeds 0.5%

NOx reduction efficiency should be 90% when O₂ in is less than 0.5%. This test may require loaded mode testing and/or disabling EGR. It may also be necessary to artificially enrich the air-fuel mixture to reduce O₂ content below 0.5%

NOTE: EPA CERTIFICATIONS ONLY REQUIRES CATALYSTS TO OXIDIZE CO& HC AT 70% EFFICIENCY, AND TO REDUCE NO AT 60% EFFICIENCY. THIS MAY NOT BE SUFFICIENT TO ALLOW SOME CARS TO PASS ASM TESTS. SOME CARS MAY REQUIRE 90% EFFICIENCY IN NOx REDUCTION. OTHERS MAY BE FINE WITH LESS THAN 50%.

The oxidation and reduction efficiency of good catalysts vary due to oxygen levels in the exhaust system during normal running conditions of those cars. 2-way catalysts operating with high oxygen levels in the feed-gas should meet the above standards for CO and HC oxidation. All 3-way catalysts operating with low oxygen levels in the feed-gas should meet the above standards for CO & HC oxidation and NOx reduction.

4. LIGHT-OFF TEST

This test must be performed with the engine cold. Start the cold engine and monitor exhaust gas at 2500 rpm during warm up. Exhaust emission readings should be relatively stable except during the following three events:

1. Initial start up & stabilization.
2. Initialization of closed loop.
3. CAT converter "light-off".

This can be graphed or "traced" so that the readings before and after converter light off can be compared. Use the same formula shown in the "Invasive Test".

$$\frac{(\text{HC in}) - (\text{HC out})}{(\text{HC in})} \times 100 = \text{CAT HC efficiency}$$

$$\frac{(\text{CO in}) - (\text{CO out})}{(\text{CO in})} \times 100 = \text{CAT CO efficiency}$$

$$\frac{(\text{NOx in}) - (\text{NOx out})}{(\text{NOx in})} \times 100 = \text{CAT NOx efficiency}$$

HC oxidation efficiency should be 70%-90% when O₂ in exceeds 1% and O₂ out exceeds 0.5% you may need to induce a misfire to create the proper O₂ levels

CO oxidation efficiency should be 70%-90% when O₂ in exceeds 1% and O₂ out exceeds 0.5%

NOx reduction efficiency should be 60%-90% when O₂ in is less than 0.5%. This test may require loaded mode testing and/or disabling EGR. It may also be necessary to artificially enrich the air-fuel mixture to reduce O₂ content below 0.5%

The oxidation and reduction efficiency of good catalysts vary due to oxygen levels in the exhaust system during normal running conditions of those cars. 2-way catalysts operating with high oxygen levels in the feed-gas should meet the above standards for CO and HC oxidation. All 3-way catalysts operating with low oxygen levels in the feed-gas should meet the above standards for CO & HC oxidation and NOx reduction.

5. MISFIRE TEST

When a misfire occurs the catalytic converter releases a tremendous amount of heat as it oxidizes the unburned HC into H₂O and CO₂. The increased temperature that this causes increases the Catalyst efficiency. This reaction allows us to test the catalyst by inducing a misfire.

THE TEST:

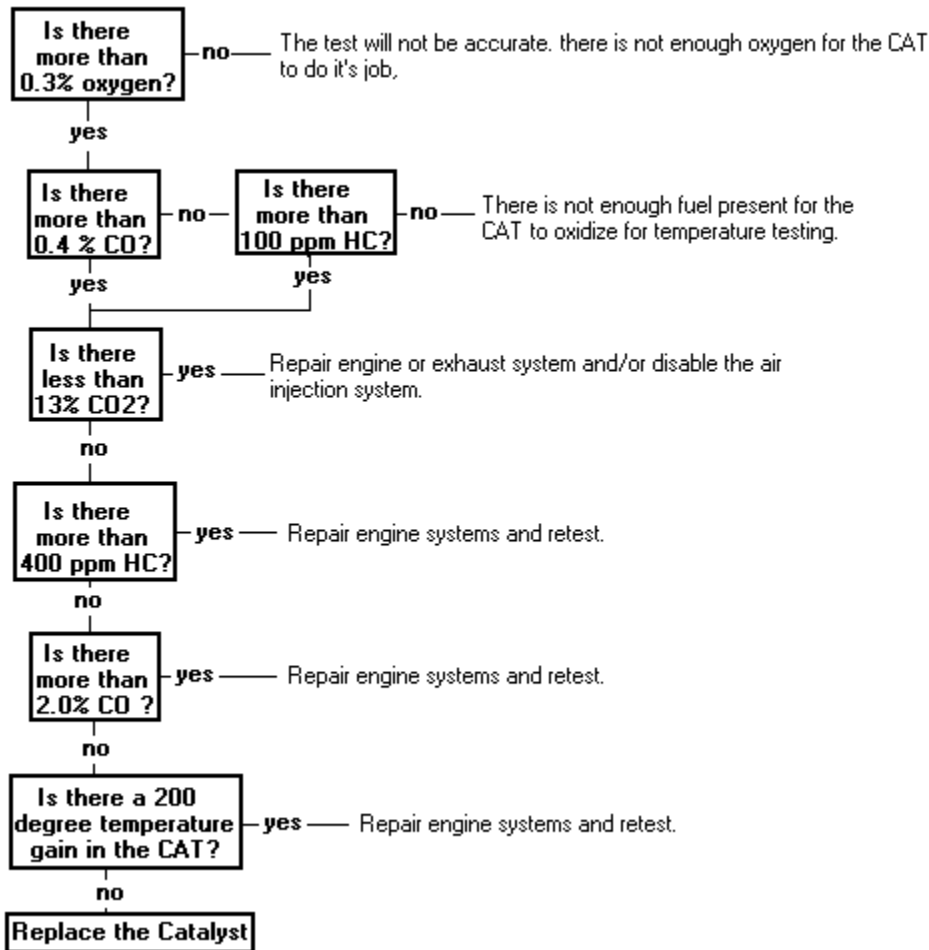
1. Allow the car to run for several minutes at 2500 rpm after it is properly warmed up.
2. Disable one spark plug. Do NOT allow the engine or exhaust system to cool down as you do this. It is permissible to turn the engine off while disabling the spark plug, but this must be done and the engine restarted within 3 minutes. Some engine analyzers will allow you to kill an individual cylinder without turning the engine off.
3. Monitor the HC level as you kill the spark plug. The HC will increase dramatically for several seconds. Then, as the catalyst heats up, the HC level drop off significantly. Record the Peak HC level and the level that HC drops to as it gets hot.

A good catalytic converter will be able to reduce the HC emissions to about 50% or less of the peak HC emissions in just a few seconds.

THIS TEST MUST BE PERFORMED WITH CAUTION. DO NOT PERFORM THIS TEST FOR EXTENDED PERIODS OR UNDER A LOAD. A CATALYTIC CONVERTER CAN OVERHEAT TO THE POINT OF MELT-DOWN IN AS LITTLE AS 12 SECONDS IF ALL SPARK PLUGS ARE DISABLED WHILE UNDER LOAD. DO NOT DISABLE MULTIPLE CYLINDERS AND DO NOT PERFORM THE TEST UNDER ROAD LOAD OR DYNE CONDITIONS.

6. TEMPERATURE & 4-GAS TEST

Completely warm up the engine and exhaust system. Run the following test using a 4 or 5-gas analyzer and an infra-red temperature sensing gun.



The accuracy of infra red temperature sensing varies according to the "emissivity" of the surface being sensed. Sometimes it is helpful to paint the surfaces with a quick drying flat black paint before testing. Painting is recommended if the two surfaces have different surface finishes.

7. OBDII MONITOR TEST

A properly operating catalytic converter uses oxygen to oxidize HC and CO into CO₂ and O₂. The process changes the oxygen level in the exhaust. Under tightly controlled conditions, the PCM will initiate a pattern of fuel control commands and monitor the oxygen sensor response. In order to pass the monitor test the oxygen sensor response must fall within a pre-determined pattern. The pattern is different for each car but the rear oxygen sensor is often compared to the front oxygen sensor to identify changes that the catalytic converter causes in exhaust oxygen content.

THE TEST:

The OBDII monitor test is typically run automatically on every trip in which the required enable criteria are met. The enable criteria are different on each vehicle. Details of the enable criteria and the drive cycle required to meet those criteria can be found in published service manuals.

As mentioned elsewhere in this document, many vehicles that use “exponentially weighted moving averages “ as part of the OBDII catalyst monitoring, have reduced accuracy immediately after the memory has been cleared. Under these temporary conditions, false fails and false passes are more likely to occur. With this possible exception, OBDII monitors are very accurate. If in doubt, clear codes and retest.

The gasoline used in the modern automobile is a complex blend of both straight and branched chain hydrocarbons. In simpler terms it is a mixture of different types of bunches of hydrogen and carbon. We will use the fictitious molecule C_8H_{17} to approximate the blend of different hydrocarbon compounds found in gasoline. In more simple terms one gasoline molecule* contains 8 atoms of carbon for every 17 atoms of hydrogen and nothing else*.

ONE GASOLINE MOLECULE*

GASOLINE IS --> C_8H_{17}

8 CARBON ATOMS + 17 HYDROGEN ATOMS BONDED TOGETHER

**There is no such thing as a single gasoline molecule. Gasoline is a very complex blend of several different molecules. C_8H_{17} is used to represent the average "gasoline molecule".*

COMPOSITION OF AIR

1 PART OXYGEN (O_2) AND 4 PARTS NITROGEN (N_2)

When gasoline is mixed with air and ignited in the combustion chamber it burns, and in doing so reorganizes the hydrogen, carbon and oxygen atoms. As these atoms are reorganized they can form CO , CO_2 , H_2O , NO (and other NO_x), and of course if some of the gasoline is left unburned, C_8H_{17} or other forms of generic HC.

Optimum combustion occurs at an A/F ratio of about 14.7:1. If all of the fuel vaporizes and takes part in combustion and no NO_x is formed we would have perfect combustion. Perfect combustion would result in the formation of nothing but CO_2 , H_2O .

Perfect combustion: Air + Fuel \rightarrow CO_2 + H_2O (and nothing else)

Unfortunately, as more and more CO_2 is formed the temperature goes up. As the temperature increases, NO_x is formed. NO_x formation uses up the oxygen that is needed for CO_2 formation

Real World combustion: Air + Fuel \rightarrow CO_2 + H_2O + NO_x + CO (and unburned HC, O_2 & N_2)

NO_x emissions are at their highest between 14.7:1 and about 16.5:1

HC emissions increase whenever the mixture is richer or leaner than about 14.7:1. Under lean conditions, the fuel charge will sometimes fail to ignite and result in high HC emissions. This is known as a lean misfire. Under rich conditions, some of the fuel fails to burn because there is not enough oxygen.

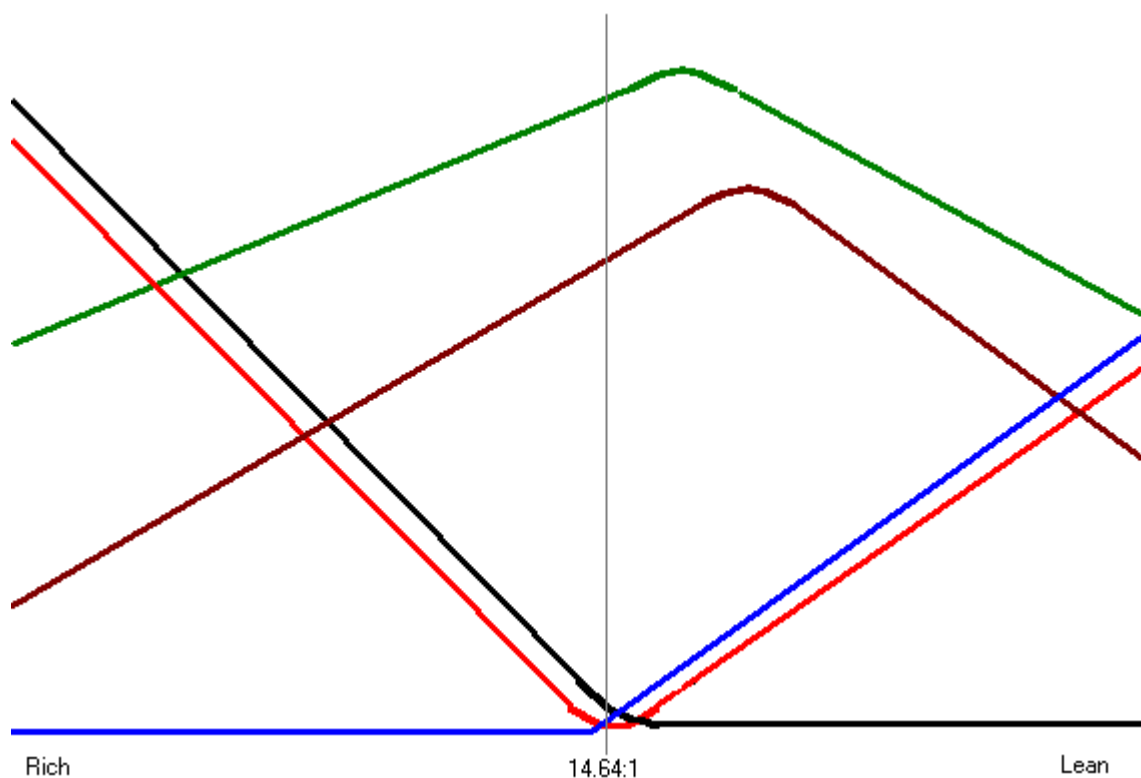
KEY CONCEPTS:

- 1. The amount of oxygen present determines what emissions the fuel will produce when burned.**
- 2. As we approach perfect combustion the increased temperature causes additional pollutants to start forming.**
- 3. We can never achieve perfect combustion inside the engine.**

CO emissions increase under conditions richer than 14.7:1 and when NOx emissions increase near 14.7:1.

The amount of energy (power) released during this reorganization of atoms (combustion/chemical reaction) depends upon the ratio of gasoline to oxygen and the new compounds that are formed. The following is a list of the amount of energy (power) that is released when different compounds are formed. This list shows how much energy is released when one molecule of each compound is formed.

Carbon monoxide exothermic)	CO = 110.5 KJ/mole (releases heat /
Carbon dioxide heat/exothermic)	CO ₂ = 393.5 KJ/mole (releases
Water (steam) exothermic)	H ₂ O = 241.8 KJ/mole (releases heat /
Unburned fuel exothermic)	HC = 0.0 KJ/mole (releases heat /
Nitric oxide endothermic)	NO = -90.4 KJ/mole (absorbs heat /



As the air/fuel mixture approaches 14.64:1, the high combustion temperatures (2500 degrees and higher) inside the combustion chamber cause the nitrogen and carbon to compete for oxygen. This prevents perfect combustion from taking place inside the combustion chamber.

KEY CONCEPTS:

- 1. An air/fuel mixture of 14.7:1 is the best compromise but it does not provide perfect combustion.**
- 2. A 14.7:1 mixture gives the lowest CO and HC levels but it also produces very high NOx levels.**
- 3. A 14.7:1 mixture also results in low oxygen levels.**

Misfire:

Single cylinder misfires are completely ignored by the traditional 5-gas graph. Partial misfires that are not related to an overall lean condition are also ignored. The following chart can be very useful in helping to identify single cylinder misfires and partial misfires.

	Normal	No spark	No fuel
CO ₂	15.0%	0.0 %	0.0%
CO	0.5%	0.0%	0.0%
HC	20 ppm	6000 ppm	0 ppm
O ₂	0.5 %	20%	20%

The chart serves to remind us what really happens to the exhaust emissions when a single cylinder misfire or partial misfire occurs.

EXAMPLE#1: one fouled spark plug on a four-cylinder engine.

Three “normal” cylinders + one “no spark” cylinder

$$\begin{aligned} \text{CO}_2 &= \{3(15.0\%) + 1(0.0\%)\} \text{ divided by } 4 &= 11.25\% \text{ CO}_2 \\ \text{CO} &= \{3(0.5\%) + 1(0.0\%)\} \text{ divided by } 4 &= 0.375\% \text{ CO} \\ \text{HC} &= \{3(20 \text{ ppm}) + 1(6000 \text{ ppm})\} \text{ divided by } 4 &= 1515 \text{ ppm HC} \\ \text{O}_2 &= \{3(0.5\%) + 1(20\%)\} \text{ divided by } 4 &= 5.375\% \text{ O}_2 \end{aligned}$$

Even without doing any math, the chart can be used to quickly remind us that the fouled spark plug will increase O₂ & HC and decrease CO & CO₂. The increased O₂ is not often considered a problem, but it can dramatically reduce the catalytic converters ability to reduce NOx emissions. Even intermittent or partial misfires can increase exhaust oxygen enough to prevent adequate NOx reduction and cause an ASM emission failure.

The chart ignores any PCM response to misfires. This fact makes it particularly useful on non-computer controlled cars. It is also very useful in preparation for ASE L1 and state smog exams. Many ASE test questions are based on the assumption that there is no computer, or that the computer has not yet reacted to the fault.

NOx control & failure analysis

1. **Ignition Timing.** Advanced ignition timing increases peak combustion pressures and temperatures resulting in increased NOx emissions. A small increase in base timing can also increase the PCM advance resulting in much greater ignition advance under load. This is a very common cause of ASM NOx failures on cars with adjustable distributors.
2. **EGR.** EGR reduces peak combustion temperature and pressure by slowing the rate of combustion. There are numerous things that can go wrong with these systems. Carbon can restrict the EGR passages. The EGR diaphragm can leak. Vacuum controls can leak or become restricted. PCM controls can fail or be altered. EGR faults are a very common cause of ASM NOx failures. Any change in exhaust backpressure can dramatically alter EGR system performance. Replacement catalytic converters that reduce exhaust pressure can disable EGR function resulting in gross NOx emissions.
3. **Catalytic converter.** Under ideal conditions, a three-way catalyst can reduce somewhere between 30% and 99% of NOx emissions. But, a traditional catalyst will not reduce NOx unless exhaust oxygen level is very low. Lean burn engines require special catalysts that will still reduce NOx at higher oxygen levels. Backpressure transducer EGR systems will not operate properly if the exhaust system has been modified in a way that reduces backpressure.

The Environmental Protection Agency (EPA) approves the use of replacement catalysts (Outside California and under certain conditions only) with extremely low oxidation (HC & CO) and reduction (NOx) efficiency. EPA also approves converters that can prevent EGR from operating properly. These EPA approved converters have frequently failed to pass California emission inspections. In the past, California Air Resources Board (CARB) has had replacement catalytic converter approval requirements that were only slightly better than EPA requirements.

Outside California EPA approval requirements allow replacement converters that could increase NOx emissions from 7 ppm to 700 ppm on fairly typical cars. Previous CARB approval requirements could still increase NOx emissions from 7 ppm to 500 ppm under similar conditions. These ineffective requirements resulted in approval of some replacement converters that were not capable of passing California emission inspections.

In the past, EPA and CARB approval of low efficiency converters inappropriately encouraged technicians to select much larger converters for certain applications. This required technicians to ignore direct fit converters and select the largest converters approved for the engine displacement and gross vehicle weight (GVW). In many cases this would allow the vehicle to pass the California ASM or TSI emission test. But, emissions could actually increase under some other operating conditions. The reduced exhaust restriction could also disable EGR function on some vehicles resulting in dramatic increases in NOx emissions under a wide variety of operating conditions (including ASM testing).

If the above was not bad enough, many perfectly good OEM catalytic converters were misdiagnosed and replaced with substandard EPA and CARB approved aftermarket converters. This has resulted in needless expense for consumers and increased vehicle emissions.

Catalytic converters should never be replaced without adequate testing. The cause of failure should always be confirmed before replacing a catalyst. Fuel metering problems, misfires and other faults can quickly destroy a new catalyst. OEM converters and the new generation of CARB approved converters are not cheap! Care should be taken to insure that original converters are defective and that any conditions that might damage a catalyst are fixed before replacing any catalyst.

4. **Lean air/fuel mixture.** Lean air/fuel mixtures increase NOx emissions and prevents the catalyst from reducing NOx. This double impact causes tailpipe NOx emissions to be much more than typical 5-gas emissions graphs would indicate. A lambda fuel mixture calculation should be done to accurately determine fuel mixture.
5. **Fuel injector imbalance.** Fuel injection nozzles can become fouled or restricted. This can cause some cylinders to be lean while others are rich. The combination can cause emissions failures even though the overall mixture is correct.

Routine cleaning or flushing of injection nozzles is not recommended by car manufacturers and is not beneficial or appropriate as a scheduled maintenance operation. The benefits that such a service may appear to show in some tests are extremely short lived and therefore not cost effective or responsible. The regular use of Top Tier approved gasoline (see www.toptiergas.com) is usually sufficient to keep the entire fuel injection system clean without any need for injection flushing or cleaning services. Injection nozzle cleaning should only be recommended or performed when there is evidence to indicate a legitimate need.

- 6. Carbon deposits.** Carbon deposits increase compression ratio and create hot spots. Both of these increase NO_x emissions. Carbon formation is accelerated by rich air/fuel mixture. Because of this, many cars that fail an ASM test with high CO levels, fail with high NO_x emissions after the CO problems are repaired. There are many chemical treatments that can be used to remove carbon deposits. Systems that introduce the chemical directly through the fuel injection rail (not the fuel tank) seem to work the best.

Routine combustion chamber cleaning services are not recommended by car manufacturers and are not beneficial or appropriate as a scheduled maintenance operation. The benefits that such services appear to show in some tests are extremely short lived and therefore not cost effective or responsible. The regular use of Top Tier approved gasoline (see www.toptiergas.com) is usually sufficient to keep the combustion chambers and valves sufficiently clean without any need for scheduled combustion chamber cleaning services. Combustion chamber cleaning services should only be recommended or performed when there is evidence to indicate a legitimate need. A documented history of deposit problems on a specific vehicle operating under specific conditions would justify recommending such a service.

- 7. Exhaust restriction.** Restricted exhaust increases engine load and increases heat buildup in the combustion chamber. This not an extremely common problem and is therefore often overlooked. Errors in calculated or inferred BARO values are common when exhaust restriction is excessive. This can result in an ASM NO_x failure that the OBDII system fails to identify (No-codes).
- 8. Engine temperature.** Engine overheating can easily cause a NO_x failure. Simply forgetting to use an auxiliary cooling fan can cause a car to fail an ASM test with high NO_x emissions. The heat load of air conditioning compounds this problem. Test all cars with A/C off and an approved auxiliary cooling fan. Known cooling system problems should be repaired before having an emissions test.
- 9. Cooling system restrictions.** Restrictions in cooling passages can theoretically cause individual cylinders to be hot enough to cause NO_x emissions failure without any obvious symptoms of overheating. One suggested cause of this is old freeze plugs that have been left inside the engine block. There are no documented cases of this ever actually occurring.
- 10. Intake air temperature.** This is not as common as rumored. In most cases, computer controlled cars can allow for any foreseeable intake temperature without a NO_x failure. If the IAT sensor indicates a temperature that is higher than actual, some cars will under calculate MAF & LOAD resulting in increased computer advance and reduced EGR commands. This can result in an ASM NO_x failure that the OBDII system fails to identify (No-codes).
- 11. Fuel octane.** Fuels that are lower octane than the car is designed for can dramatically increase NO_x emissions. Most cars are designed for low octane fuel so this is not a common problem. Carbon deposits can increase a cars octane requirement. This is best addressed by cleaning out the carbon, NOT switching to high octane fuel.

12. **Spark plug heat range.** This can effectively create a hot spot that in extreme cases can cause a NOx failure.
13. **Spark plug gap.** Increased spark plug gap, especially combined with high performance ignition modifications can have an effect similar to advancing ignition timing. The effect is fairly minor, but can be significant when combined with other problems or modifications.
14. **Compression ratio.** Major engine repairs can and do change compression ratio. Cylinder heads are frequently milled. Different brands of gaskets have different compressed thickness. Increased compression ratio can cause ASM NOx failure that the OBDII system fails to identify (No-codes).
15. **Combination Failures.** Several minor problems can combine to create a NOx failure. EXAMPLE: A relatively slight MAF error can result in load calculation error that results in advanced ignition timing reduced EGR, lean A/F mixture and increased exhaust oxygen. Each of these individually increases tailpipe NOx emissions. The combined impact can sometimes cause an ASM NOx failure without failing OBDII monitors.

KEY CONCEPTS:

1. *EGR and catalytic converters play a huge role in NOx emission control.*
2. *Catalytic converters impact the performance of EGR systems and can disable EGR systems.*
3. *Many other systems impact the performance of catalysis and EGR systems which can lead to misdiagnosis.*
4. *Original equipment catalytic converters often outperform EPA approved aftermarket replacement converters by a fairly wide margin.*
5. *When several fairly minor problems combine, NOx failures may occur that the OBDII system fails to identify.*

EGR systems and NOx control

EGR is one of the most effective NOx reduction systems in use. An EGR system that is inoperative or just restricted will usually cause a NOx failure on an ASM/loaded mode test. On many engines, EGR will reduce NOx emissions by 1000 ppm or even 2000 ppm. A related document addresses the following EGR systems in more detail:

1. Basic ported vacuum operated EGR valve system.
2. Vacuum amplifier EGR systems.
3. External backpressure transducer EGR systems.
4. Internal positive backpressure transducer EGR valves.
5. Internal negative backpressure transducer EGR valves.
6. PCM controlled vacuum operated EGR valves (single solenoid).
7. PCM controlled vacuum operated EGR valves (dual solenoids).
8. Digital/electric solenoid EGR valves.

Exhaust Backpressure & NO_x Emissions

There has been much speculation that exhaust system modifications may cause increased NO_x emissions and loaded mode smog test failures. The theory is that a free flowing after-market exhaust system will reduce exhaust pressure and therefore reduce EGR flow. It seems logical that any decrease in exhaust back-pressure would decrease EGR flow. EGR is the primary NO_x system, so it stands to reason that reduced exhaust back-pressure would increase NO_x emissions. In the real world this does not always happen. In order for us to accurately diagnose NO_x emissions failures we must understand why.

Other factors besides exhaust pressure are affected by decreased exhaust system restriction. Reduced restriction also improves the flow of heat out of the combustion chamber on the exhaust stroke. This helps reduce combustion chamber temperatures and therefore reduces NO_x temperatures. The improved exhaust flow and reduced exhaust pressure also reduces required combustion chamber pressures for a given engine speed and power output. This reduction in pressure also results in reduced combustion temperatures. These factors also result in increased intake manifold vacuum for any given engine speed and load.

The above factors certainly indicate that reduced exhaust back-pressure may reduce NO_x emissions. But EGR is still a major influence on NO_x emissions so let's look at how EGR flow will really be affected by a change in exhaust restriction.

The amount of EGR flow depends on the following three things:

1. Intake manifold vacuum.
2. Exhaust pressure.
3. Restrictions in the EGR valve and passages (primarily the valve itself).

As exhaust back-pressure decreases due to reduced restriction the intake manifold vacuum tends to increase (assuming horsepower and rpm remain constant). This means that if the EGR valve position does not change, the actual EGR flow would not necessarily change as exhaust pressure changes.

EGR valves with positive back-pressure transducers will leak vacuum and fail to open at idle and with the engine off. Negative back-pressure transducers will hold vacuum with the engine off, but leak vacuum at idle. The transducers are integrated into many EGR valves. Some systems have separate transducer assemblies mounted next to the EGR valve. It is typical for transducers to partially seal under normal engine loads. This partial sealing is part of the normal EGR control.

Cars that use back pressure transducers will tend to have a significant change in EGR flow when exhaust systems are modified. The reduced back pressure will delay, or prevent the EGR valve opening. Negative back pressure transducers depend on scavenging to reduce exhaust pressure at idle and prevent EGR operation. Increasing exhaust flow can continue this effect and delay or prevent EGR operation under load. Negative back pressure transducers are hard to predict when the exhaust system is modified because exhaust scavenging is not always enhanced by enlarging the exhaust system. In these systems EGR might even open sooner causing hesitation and surge complaints. Increasing exhaust size/volume will almost always delay and reduce EGR flow on positive back pressure systems.

Computer systems that have pressure or temperature EGR feedback sensors will generally increase EGR valve opening to compensate for slight to moderate restrictions in the EGR passages, back pressure etc. Systems that use position sensors have no way of compensating for deposit restrictions.

Computers and conventional EGR systems may respond to slight reduction in throttle position (TPS and ported vacuum signal controls) caused by reduced exhaust back pressure.

If you have a back-pressure transducer EGR system, reducing exhaust restriction is likely to cause a significant decrease in EGR flow. Any other system is far less likely to be affected this way. This is consistent with the results that technicians have experienced in "real world" loaded mode emissions testing.

KEY CONCEPTS:

- 1. Increased exhaust backpressure increases NOx emissions**
- 2. Increased exhaust backpressure can cause AIR to back up into the NOx reduction bed of the converter and prevent NOx reduction.**
- 3. Decreased exhaust restriction may reduce EGR flow on some cars and result in increased NOx emissions**

THE CATALYST

Catalysts are needed to reduce emissions to acceptable levels without dramatically reducing performance and fuel economy. This is true of HC, CO and NOx, but NOx is the emission that is most dependent on the catalyst for emissions compliance.

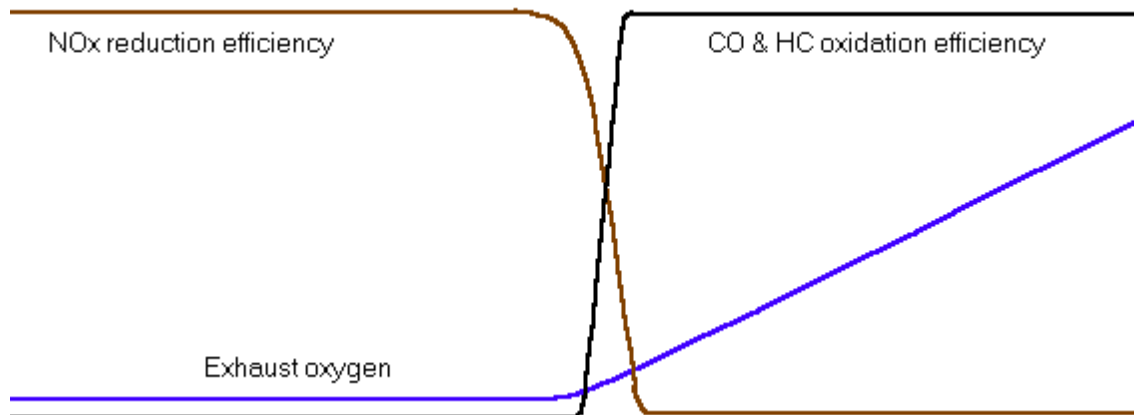
There are actually two types of catalysts. Reduction catalysts cause NOx to be reduced into O₂ and N₂. Oxidation catalysts cause HC and CO to oxidize with any available oxygen into CO₂ + H₂O. Unfortunately oxidation will only occur when there is enough free oxygen, and reduction is very hard to achieve with the high oxygen levels that occur in lean burn operation.

Rhodium with platinum is generally the most efficient reduction catalyst. Platinum and palladium are used for oxidation. Newer lean burn cars with higher exhaust oxygen content rely on much greater use of the rhodium/platinum composition for reduction.

2-way catalytic converters are oxidation catalysts. They oxidize CO and HC but do not reduce NOx. 3-way catalysts oxidize and reduce. They oxidize CO & HC and reduce NOx.

Proper air/fuel mixture control and exhaust oxygen content is required for proper 3-way catalyst performance. In general, oxidation and reduction cannot both occur at their highest efficiency at the same time.

Reduction efficiency is not at its highest unless the oxygen content is very low. This usually doesn't happen unless the air/fuel mixture is at least a little bit rich. Oxidation only reaches its highest efficiency when the oxygen content is fairly high. That happens when the mixture is at least slightly lean.



KEY CONCEPTS:

- 1. A catalyst cannot clean up CO and HC unless there is enough oxygen in the exhaust.**
- 2. Many catalysts cannot clean up NOx unless the level of oxygen in the exhaust is very low.**
- 3. There is no fuel mixture that allows CO, HC and NOx to all be catalyzed at maximum efficiency.**

A dual bed catalyst has two separate chambers. Air can be injected in the middle of the catalyst to increase oxygen content in the back half of the converter. The engine can then be run slightly rich to improve NOx reduction in the front half of the converter. The air that is injected allows high efficiency oxidation of CO & HC in the back half of the converter. This type of converter can allow NOx reduction to occur in the front bed at maximum efficiency while CO and HC oxidation are occurring in the rear bed at maximum efficiency. It is the injection of air in front of the rear bed that allows both oxidation and reduction to occur at maximum efficiency.

For the dual bed catalyst to operate at maximum efficiency, it must have very low oxygen levels in the exhaust entering the front bed. This only occurs when the engine is running slightly rich with no misfires or deposit problems. It must also have enough air injected in front of the rear bed to allow oxidation of the CO and HC.

The front bed of a dual bed catalyst does also oxidize CO and HC. Even a rich mixture will leave some oxygen in the exhaust. The catalyst uses this small amount of oxygen to oxidize CO & HC into CO₂ & H₂O. As NO_x is reduced, oxygen from that NO_x is freed up. If this extra oxygen was allowed to accumulate it would start to limit NO_x reduction. But the oxygen from the NO_x is used to oxidize CO and HC. This limits oxygen build-up in the front bed and keeps NO_x reduction at maximum efficiency.

KEY CONCEPTS:

- 1. A dual bed catalyst depends on air injection to provide the oxygen to clean up CO & HC when the mixture is rich.***
- 2. Air is only injected into the rear bed.***
- 3. Dual bed catalysts allow richer fuel mixtures to be used to help control NO_x .***

Many cars do not have air injection. Without air injection and a slightly rich mixture these cars must depend on something else to manage the oxygen in the catalytic converter. Cerium is an element that attracts oxygen. Under high oxygen conditions the cerium will absorb oxygen and allow NO_x reduction to occur with greater efficiency. Under low oxygen conditions the cerium will release its stored oxygen to increase the oxidation efficiency of CO and HC. Cerium is very important in many 3-way catalysts. Even dual bed catalysts benefit from cerium. The cerium can allow the front bed of a dual bed catalyst to continue reducing NO_x at close to maximum efficiency without a rich mixture.

Cerium has its limitations. It will only absorb small amounts of oxygen and it can only release as much oxygen as it has absorbed. Cerium allows the catalyst to operate efficiently under slightly rich and slightly lean conditions only for very short time periods. If the air/fuel mixture is continuously cycled from slightly rich to slightly lean, cerium can allow it to constantly operate at maximum efficiency.

In traditional fuel control systems, the main purpose of the O₂ sensor is to keep the oxygen level in the exhaust near stoichiometric. This is often achieved by constantly cycling the system slightly rich and slightly lean. If the oxygen level in the exhaust stabilizes at a mixture other than stoichiometric, the efficiency of most catalytic converters will drop. In order for a catalyst to best clean up NO_x, the A/F ratio must be richer than 14.7:1. However, NO_x emissions from the engine are highest when the engine is lean.

At 14.7:1 most catalysts can do an adequate job of cleaning up CO & HC and NO_x. But, these systems typically swing richer and leaner than 14.7:1 in response to constantly changing conditions, normal wear and manufacturing tolerances. Three way catalysts (TWC s) partially overcome this problem by using cerium for oxygen storage. This oxygen storage trick can increase the efficiency of the TWC when the oxygen level is cycling slightly rich and slightly lean

The traditional way that proper exhaust oxygen level and oxygen cycling can be maintained is with O₂ sensor feedback. This is called closed loop. After the computer has used other sensors to determine the proper fuel metering (injector on time), the O₂ sensor is used for feedback to fine tune fuel metering and to make the oxygen content in the exhaust fluctuate slightly.

KEY CONCEPTS:

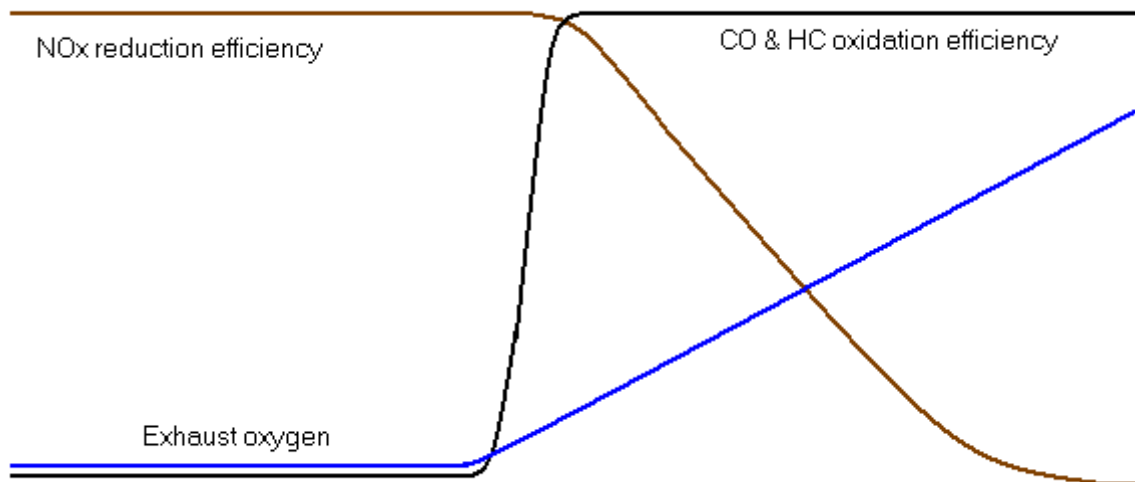
1. ***Cerium is required for proper catalyst operation (especially without air injection).***
2. ***Cerium cannot do its job if the air/fuel mixture is not properly controlled.***
3. ***Proper oxygen sensor function is required for proper catalyst function.***

Newer sensing and control strategies, and new exhaust sensors allow much better control of A/F mixture and a wider range of mixture ratios. These new systems include:

- Dual element current managed wide band oxygen sensors (Bosch, Honda, NTK).
- Single element current managed wide band oxygen sensors (Toyota).
- Biased fuel control based control typical zirconium dioxide oxygen sensors.

In lean burn applications a different type of catalyst is used. Increased use of the rhodium/platinum composition in these converters allows increased NO_x reduction under lean burn and high exhaust oxygen conditions.

Gasoline Direct Injection (GDI) engines and Homogeneous Charge Compression Ignition (HCCI) engines operate under lean burn conditions frequently. Hybrid electric vehicles often operate their internal combustion engines for shorter periods of time that would prevent traditional catalytic converters from reaching operational temperatures.



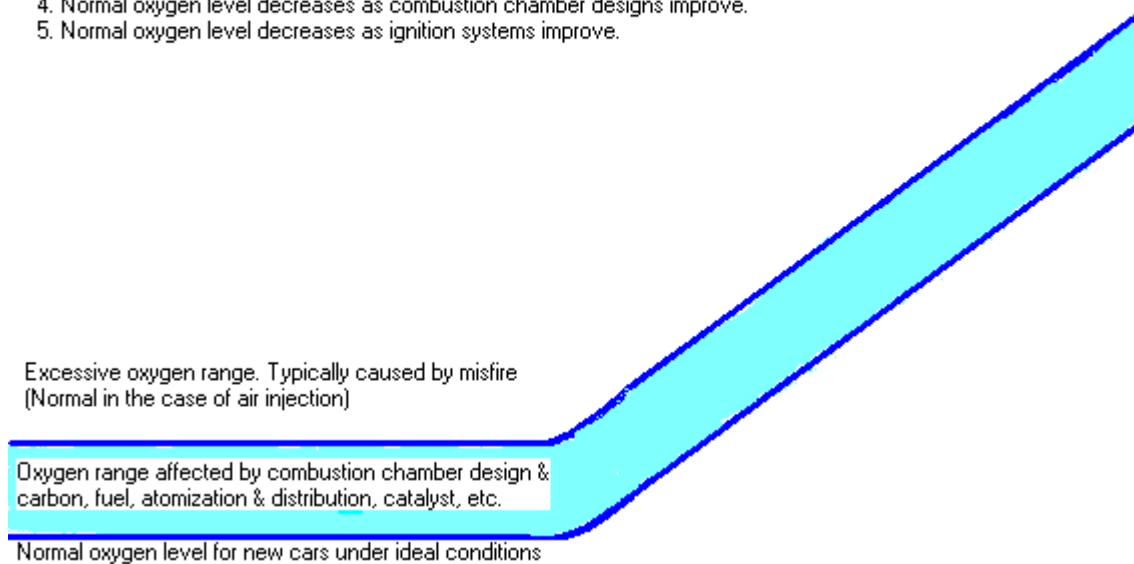
KEY CONCEPTS:

1. ***Cerium is not required in some newer lean burn catalysts.***
2. ***Lean burn catalysts can reduce NO_x at much higher oxygen levels.***
3. ***Proper oxygen sensor function is still required for maximum catalyst function.***
4. ***Very specialized catalytic converters are required in many new “high-tech” vehicles.***

Oxygen variables:

Conventional 5-gas training and a review of the standard 5-gas graph indicate that CO and O₂ levels do not rise or fall together. Anytime CO increases, O₂ falls. Likewise anytime O₂ increases, CO decreases. The past two decades of advancing automotive technology have revealed numerous exceptions to these commonly held beliefs. So much for conventional 5-gas graphs and training!

1. Normal oxygen level decreases as fuel delivery is improved. I.E.: Carburetion ->TBI ->Port injection -> sequential injection -> tuned port injection.
2. Normal oxygen level decreases (with CO) as catalyst efficiency increases.
3. Normal oxygen level increases as deposits accumulate in the injectors, intake system and combustion chambers.
4. Normal oxygen level decreases as combustion chamber designs improve.
5. Normal oxygen level decreases as ignition systems improve.



The above graph depicts the wide variation in exhaust oxygen levels that are NOT attributed to component failures. I emphasize that the exhaust oxygen changes of this type are not associated with a corresponding change in CO. Advancements in fuel injection and combustion chamber design have dramatically lowered the exhaust oxygen level of newer cars. This has greatly improved the catalysts ability to reduce NO_x emissions.

Many late model cars depend heavily on the catalyst to reduce NO_x at extremely high levels (95+ %). This simply is not possible unless the oxygen level is low enough. If carbon deposits or other problems increase the exhaust oxygen level, a perfectly good catalyst will operate at reduced efficiency.

During the compression stroke, air and fuel “hide” in the sponge carbon that forms inside the combustion chamber. The flame front of combustion is quenched or snuffed out as it approaches this carbon layer and the comparatively cool surfaces of the combustion chamber. Any gap, crevice or carbon layer serves as a hiding place for air and fuel.

Automotive engineers have responded to this by moving rings higher on the piston and reducing other gaps and crevices. The combustion chamber swirl effects of some newer designs help reduce flame quenching with a corresponding drop in HC and O₂ levels. Increasing thermostat temperatures and combustion chamber surface temperatures is another way that this issue has been addressed.

These design modifications have helped reduce the normal exhaust O₂ and HC levels. However, carbon deposits are still a significant problem. The PCM responds to the elevated O₂ level by adding fuel. This additional fuel tends to increase the CO and HC level. The catalytic converter uses the elevated O₂ levels to increase oxidation of both CO and HC. This tends to eliminate any increase in tailpipe HC and CO. The carbon layer also acts as an insulator and increases compression by taking up space in the combustion chamber. The result of this is an increase in NO_x production. The increase in NO_x production is exaggerated by a simultaneous decrease in the catalyst's ability to reduce NO_x. While the catalyst's ability to oxidize CO & HC was enhanced by the O₂ increase, its NO_x reduction efficiency was inhibited. The ability of a catalytic converter to reduce NO_x is almost completely eliminated as the O₂ level approaches 2.0%.

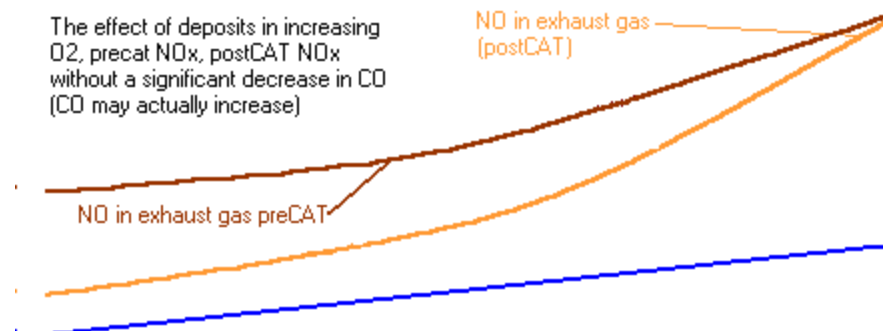
KEY CONCEPTS:

- 1. Some late model cars depend on the catalyst to clean up over 99.3% of their NO_x emissions.**
- 2. This will only occur if the exhaust oxygen level is very low.**
- 3. Many minor problems can increase exhaust oxygen levels and inhibit catalyst efficiency.**

Deposit Control, Emissions Failures and catalysts:

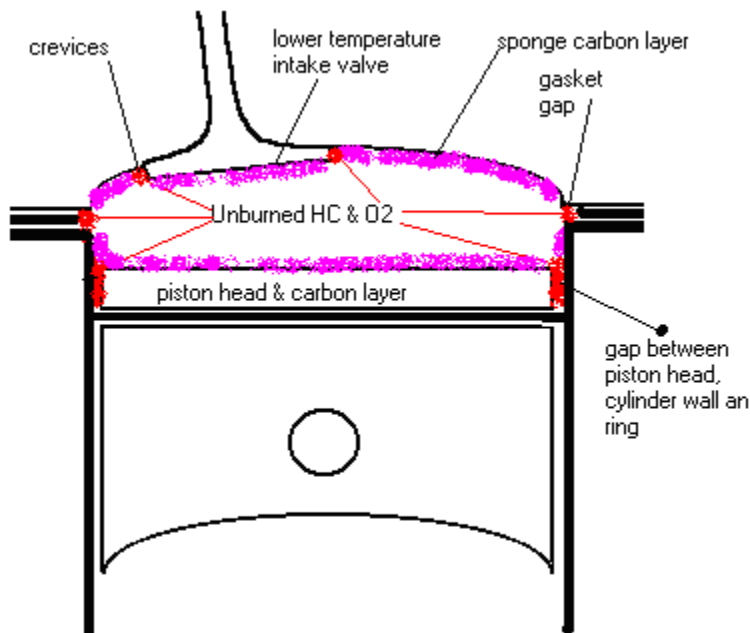
Although long ignored, deposit formations are responsible for a significant number of ASM smog test failures. They are also responsible for a variety of drivability problems. These deposits form primarily in the following areas:

1. Combustion chamber
2. The backside of intake valves
3. Throttle body
4. Injection nozzles
5. EGR ports



When there is evidence of deposits in one of these areas, you should assume that the other areas are also affected. Most deposits will increase both the engine's emissions and the converters inability to clean up those emissions. NO_x is the emission most affected by deposits.

These deposits increase compression ratio by taking up space in the chamber. They also retain heat and provide a "quenched" area for HC and O₂ to hide from combustion. NO_x emissions and detonation/pre-ignition are increased due to the retained heat from an even carbon layer; hot spots caused by small chunks of carbon, and increased compression ratio. HC & O₂ emissions are increased when the atomized/vaporized fuel mixture is absorbed into the carbon layer during the compression stroke, protected from combustion by the flame quenching effect of the carbon layer, and then exits the carbon layer during the pressure drop that occurs on the exhaust stroke. CO emissions are increased as a result of the increased O₂ levels. The high O₂ level reduces the O₂ sensor voltage. The engine control system responds to this low O₂ sensor voltage by increasing fuel delivery. *Note: pouring water into a running engine to steam blast carbon away can actually increase NO_x emissions because of the small, very hot, chunks of carbon that this method tends to leave behind.*



KEY CONCEPTS:

- 1. Injection nozzle and carbon cleaning is grossly oversold.**
- 2. Top Tier gasoline and OEM approved oil usually eliminates the need for such services**
- 3. Under some conditions these services are needed but technician should identify a specific need before recommending them.**

OBDII Catalyst Monitors

OBDII systems have methods of adapting to gradual changes in system components and system operation. Because of this, they also have accelerated learn strategies that kick in after the memory has been cleared. These two factors can cause false monitor failures when a converter is first replaced. Many technicians have observed that new catalytic converters experience a delayed light-off when first installed. Using a scan tool to turn off a check engine light will often also put the PCM into a rapid learn mode that allows the catalyst monitor to run repeatedly until patterns are relearned. This can cause repeat failures and turn the check engine light right back on, until the break-in period is over.

Ford, GM, some Chryslers, some Hondas, and possibly other cars, use "exponentially weighted moving averages" (EWMA) to help monitor catalyst function. This strategy has a "fast initial response" after the memory is cleared. This combined with the delayed light-off that has been reported on some new catalysts can cause accelerated catalyst monitors (multiple monitors within a drive cycle). This can possibly result in false failures and false passes during the first few days.

It is best to treat any OBDII fault codes, EXCEPT catalyst fault codes, that appear after converter replacement as soon as possible. They are indications of faults that could destroy the new converter. Converter fault codes should be addressed differently. They should not be taken too seriously until after the OBDII system has had plenty of time to rebuild an accurate history of catalyst performance. On some cars the technician may wish to clear codes a second time and restart the OBDII learn process. That is perfectly acceptable if all other systems have been validated.

KEY CONCEPTS:

- 1. OBDII monitors work very well most of the time and should be used to help identify faults that could damage a new catalyst.**
- 2. Immediately after clearing memory, the catalyst monitor is more likely to have a false fail or false pass as it attempts to quickly re-establish a memory**

CATALYST SELECTION CRITERIA

As of January 1, 2009 California approval requirements for all aftermarket replacement catalytic converters have changed. California Air Resources Board (CARB) has always had more stringent catalytic converter requirements than the EPA. The new changes increase requirements in order to insure that aftermarket replacement catalytic converters come closer to the performance of original equipment converters. This should increase the chance of aftermarket converters passing California emission inspections. It should also extend the life of aftermarket replacement converters. The result of these changes is:

- Increased ease of appropriate selection for technicians
- Increased emission reduction performance
- Increased overall value to consumers.

CARB no longer allows catalytic converter selection based on GVW and engine displacement. It is now illegal (in California) to select a catalytic converter for installation based solely on vehicle weight, engine size, physical shape, size configuration or pipe diameter. This change addresses the common problems outlined previously in this document.

Aftermarket replacement catalytic converters must now be selected based on the CARB approval for the specific vehicle application as listed in the converter manufacturers California catalog or other California specific application listing. It is the technician's responsibility to confirm that the appropriate converter or converters are selected and properly installed.

Some similar vehicles have multiple factory configurations. The technician should confirm:

- Dual converters are replaced with dual converters
- Rear converters are installed in the rear position
- Front converters are installed in the front position
- The converter has a CARB Executive Order (EO) number, part number, production date and directional flow arrow embossed into the converter shell #.
- Directional converters are installed in the proper direction.

A few early production applications of the new CARB approved converters have a plate bearing this data welded onto the converter shell. These have been accepted by CARB but all new/future installations should be embossed.

OBDII Converters

OBDII catalytic converters are even more critical. Their performance and placement must match that of the original closely enough to insure proper performance of the OBDII monitor system. The CARB certification process for OBDII applications is much more stringent than the EPA approval requirements. It is the technicians' responsibility to insure that any aftermarket replacement converter is CARB OBDII certified for the specific application.

KEY CONCEPTS:

- 1. California has new stricter catalytic converter approval and certification requirements.**
- 2. These new requirements assure much better emission reduction performance.**

Catalytic Converter Replacement Requirements

Technicians and vehicle owners do NOT have the option of replacing original equipment catalytic converters without first meeting numerous requirements. ALL of the following conditions must be met before an OEM converter can be replaced with an aftermarket converter:

- a) The exact vehicle is specifically included in the vehicle application list for which the new aftermarket catalytic converter has been exempted;
- b) The vehicle is more than 7 years old or has more than 70,000 miles on the odometer;
- c) The vehicle is beyond the OEM catalyst warranty period (which can vary from 7 years/70,000 miles to 15 years/150,000 miles).
- d) The vehicle has a legitimate need for replacement of the existing converter that has been established and documented by the installer. The Installer must make a determination that an existing original equipment converter is not functioning properly before acting to replace it (all diagnostic tests should be carefully documented);
- e) The exempted new aftermarket catalytic converter is installed in the same location as the OEM catalytic converter it is designed to replace. The front of the installed catalytic converter shall be no more than three inches further upstream or downstream in the exhaust from where the front face of the OEM catalytic converter was located. The installation may not alter the location of oxygen sensors upstream or downstream of the catalytic converter(s).
- f) The exempted new catalytic converter is installed on a one for one catalytic converter basis; the technician can no longer use one catalytic converter in place of two or two catalytic converters in place of one.
- g) The exempted new aftermarket catalytic converter is installed with all other required catalytic converters (no two for one or one for two installations).
- h) A warranty card has been filled out by the installer, signed by the customer, attached to the repair invoice, and a copy returned to the catalytic converter manufacturer.
- i) Installers shall keep documentation regarding the installation of the new catalytic converter including all of the above information. This documentation shall be made available to CARB or its representative as provided for in title 13, section 222(b)(8). All such records shall be maintained for four years from the date of sale of the catalytic converter.

KEY CONCEPTS:

- 1. Aftermarket catalysts are only allowed under strict conditions.**
- 2. Significant documentation is required when installing an aftermarket catalyst.**

What can damage a new catalyst?

Quality catalytic converters can perform well for hundreds of thousands of miles. One of my own vehicles has over 300,000 miles on the catalytic converter and it is still working fine. However, when subjected to the right conditions, converters can become overheated and destroyed in as little as twelve seconds. Many of the converters that require replacement have failed because of some type of engine operating fault. If the fault is not identified and repaired, the converter can quickly destroy itself. This often happens in less than a week.

Anything that significantly increases the amount of HC and/or CO that is oxidized in the converter will increase the operating temperature of the catalyst. If the car has an air injection system, anything that causes a rich mixture may quickly destroy a new converter.

Failing to use low Phosphorous ILSAC approved engine oil may accelerate catalyst failure. Most phosphorous damage occurs from the "flash-off" that occurs during the first 300-500 miles after an oil change. So, changing oil more often could actually make it worse.

It is a good idea to test the exhaust emissions of vehicles before you replace the converter. Any vehicle that emits over 2.0% CO, or 400 ppm HC, probably has faults other than the converter. Many cars will have emissions much lower than that without a converter. The new catalyst may clean up 95% of these emissions; it may also destroy itself in the process.

Coolant seeping into the combustion chamber or exhaust can also damage catalysts. The ceramic substrate of the catalyst can be damaged from impacts. Lowered vehicles and off road vehicles are the most susceptible to this type of damage. Some low cost converters can sometimes shift during the expansion and contraction of normal operation. This can eventually result in misalignment and cracking of the substrate. Higher quality converters use retaining ridges and more durable "packing" materials to prevent this.

If any of the following conditions exist, the customer (or referring shop) should be notified that the engine might have existing faults that could damage the new converter:

- CO in excess of 2.0% (pre-catalyst)
- HC in excess of 400 ppm (pre-catalyst)
- Indications of high oil consumption
- Indications of combustion/coolant leaks
- Indications of O₂ sensor faults
- Indications of modifications or poor maintenance

Further diagnosis is recommended when the above conditions exist.

Check air/fuel mixture ratio. Lambda must be between 1.02 and 0.98 for best converter efficiency

Many exhaust analyzers have a lambda fuel ratio calculator. This should be used to insure that the fuel mixture is correct whenever diagnosing or replacing a catalytic converter. I can supply you with a lambda calculator program to load on your computer. This will allow you to calculate lambda from an emission test report. Contact me at crashh@prodigy.net

The use of other lambda calculators will not work properly with data from California Vehicle Inspection Reports (VIR). VIR data includes corrected HC, CO and NOx. But, the CO₂ and O₂ data is not corrected.

Dilution correction factor:

The dilution correction factor (DCF) is used to increase the HC, CO and NO_x values according to the amount of dilution identified. The DCF can increase these values by as much as three times! This means that an HC level that is displayed at 100 ppm in manual mode without the DCF may end up being as much as 300 ppm during a certified test.

The sampled level of CO₂ and the sum of CO and CO₂ are the values that are used to calculate the dilution correction factor. The following is the formula that is used to derive the DCF:

$$x = \frac{[\text{CO}_2]_{\text{measured}}}{[\text{CO}_2]_{\text{measured}} + [\text{CO}]_{\text{measured}}}$$
$$[\text{CO}_2]_{\text{adjusted}} = \frac{x}{4.644 + (1.88 \text{ times } x)} \text{ times } 100$$
$$\text{DCF} = \frac{[\text{CO}_2]_{\text{adjusted}}}{[\text{CO}_2]_{\text{measured}}}$$

(DCF is limited to a range of 1.0 to 3.0)

Technicians can use the following table to find the appropriate DCF for most cars:

DCF TABLE

CO%	8.0% CO ₂	9.0% CO ₂	10.0% CO ₂	11.0% CO ₂	12.0% CO ₂	13.0% CO ₂	14.0% CO ₂	15.0% CO ₂	16.0% CO ₂
0.1	1.90	1.69	1.52	1.38	1.27	1.17	1.09	1.02	1.0
0.2	1.88	1.68	1.51	1.37	1.26	1.17	1.08	1.01	1.0
0.4	1.85	1.65	1.49	1.36	1.25	1.15	1.07	1.0	1.0
0.6	1.82	1.62	1.47	1.34	1.23	1.14	1.06	1.0	1.0
0.8	1.79	1.60	1.45	1.32	1.22	1.13	1.05	1.0	1.0
1.0	1.76	1.58	1.43	1.31	1.20	1.12	1.04	1.0	1.0
1.2	1.73	1.55	1.41	1.29	1.19	1.11	1.03	1.0	1.0
1.4	1.70	1.53	1.39	1.28	1.18	1.09	1.02	1.0	1.0
1.6	1.68	1.51	1.38	1.26	1.17	1.08	1.01	1.0	1.0
1.8	1.65	1.49	1.36	1.25	1.15	1.07	1.0	1.0	1.0
2.0	1.63	1.47	1.34	1.23	1.14	1.06	1.0	1.0	1.0
2.2	1.60	1.45	1.32	1.22	1.13	1.05	1.0	1.0	1.0
2.4	1.58	1.43	1.31	1.21	1.12	1.04	1.0	1.0	1.0
2.6	1.56	1.41	1.29	1.19	1.11	1.03	1.0	1.0	1.0
2.8	1.53	1.39	1.28	1.18	1.09	1.02	1.0	1.0	1.0
3.0	1.51	1.38	1.26	1.17	1.08	1.01	1.0	1.0	1.0
3.5	1.46	1.33	1.23	1.14	1.06	1.0	1.0	1.0	1.0
4.0	1.41	1.29	1.19	1.11	1.03	1.0	1.0	1.0	1.0
5.0	1.33	1.22	1.13	1.05	1.0	1.0	1.0	1.0	1.0

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If the available exhaust analyzer does not have a dilution correction mode the above table should be used. The correct DCF value is selected from the chart according to sampled CO and CO₂ values. The sampled CO, HC and NO_x values are then multiplied by the DCF. The corrected values should be comparable, but not equivalent, to the readings from a certified smog machine. Certified BAR 90 and BAR 97 equipment have elaborate calibration procedures that are not found in most gas analyzers. Equivalent accuracy should not be expected.

The dilution correction factors listed in the chart (or calculated by the previously stated formula) are intended to be used by technicians who are attempting to evaluate a car's ability to pass a two speed idle (TSI) smog test. It may also be of some use in predicting a car's ability to pass an ASM test. The technician must understand that this chart matches the corrections that the ASM equipment will perform, but in no way allows for the ASM loading. It is not intended to be used to judge a car's ability to pass an IM-240 test.