



Catalytic Converters and OBD-II Monitors

Can you remember the first new car that had a catalytic converter? To sharpen your recollection, the first catalytic converters were introduced in the mid-70's when the Clean Air Act was first signed into law. The first car to meet the 1975 emissions standards was a Chrysler Avenger, and it was equipped with a rhodium-promoted platinum oxidation catalyst manufactured by Johnson Matthey. Since that auspicious introduction, the catalytic converter has continued to have a far-reaching influence on modern automobiles.

Mechanics often ask, "Why did they do that?" The answer can often be traced to what the catalytic converter does. It can be thought of as the heart and soul of the modern automobile's emissions technology. Understanding this component is as critical as understanding internal combustion theory.

Converter Construction

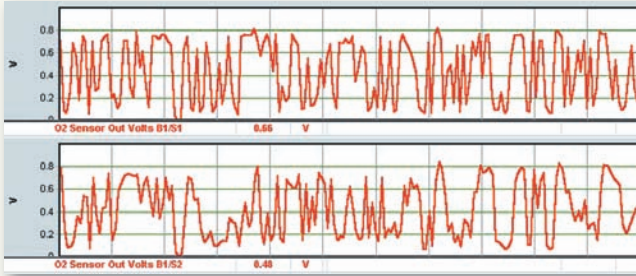
Converter construction can be broken into four major components:

- the housing
- the substrate
- the washcoat
- the catalyst.

Housing

Basic catalytic converter construction starts with the housing. Housings must withstand the rigors of the exhaust system, which include extreme temperatures and extreme temperature variations as well as corrosive environments. Cast iron and stainless steel are two housing material options. Stainless steel is a common choice, but it presents an engineering problem. Stainless expands and contracts at a different rate from than the substrate. The housing expands under the high temperatures normally seen in an exhaust environment, which may result in substrate separation.

Catalytic Converters



Here you can see the pre- and post-catalyst O₂ sensor waveforms captured using generic data stream while on a test drive. Can you tell whether the catalytic converter is OK? This one is fine.

Catalyst manufacturers have solved this problem by various means. Intumescent mats and wire mesh are two components that may be installed between the housing and substrate to take up the extra space created as the housing expands.

Substrate

Converters have evolved somewhat since the 1970's. Early converters were often full of pellets. Even when honeycomb substrates were introduced, they did not have same surface area as modern substrates. Early honeycomb substrates had 200 cells per inch, whereas newer designs have 400. This increase in surface area has a significant effect converting pollutants, especially in high volume applications. Surface volume is a crucial factor for catalytic monitors.

Washcoat

The washcoat is the coating on the substrate. It actually increases the surface area for the catalytic precious metal and provides a suitable surface area for these materials.

Precious Metals

The last components added to the converter are the precious metals. Platinum, rhodium and palladium are the three most important catalytic metals in a converter. These metals increase the speed at which the reaction takes place within the converter, from what you might describe as "trace" reactions to quantity, industrial proportions. "Promoters" can also be added to help these metals do a better job. Catalytic converter manufacturers use these components in varying quantities and various combinations to achieve particular results. The proportions of the catalytic metals also differ between various makes and models. Some models employ a warm-up catalyst as well as main converters, and each contains different substrates and combinations of precious metals.

Cost is the major factor in design and construction, and converter technology is no exception. Precious metals are very expensive. Rhodium is the most expensive, followed by platinum and palladium. Designers are always looking for ways to increase the effectiveness of these constituents, which would allow them to reduce the quantity of expensive material used. For this reason, converter construction changes constantly.

Catalytic Converter Operation

A catalyst accelerates (or facilitates) a chemical reaction. The reactions that occur within the converter *could* occur without a catalyst but at a much slower rate, glacial perhaps instead of industrial. Temperature is also important to determine catalytic-conversion rate. Within limits, the speed of a chemical reaction increases as conditions get hotter.

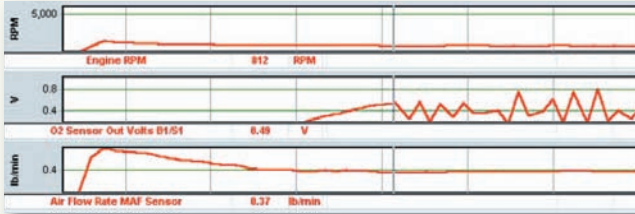
Carbon monoxide (CO) and hydrocarbons (HC) were the first pollutants the catalysts converted. Both of these pollutants can be oxidized (burned), into carbon dioxide (CO₂) and water (H₂O). Simplified oxidation formulas can be written as $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$ and $\text{HC} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$. As these simplified formulas show, combining oxygen with either HC or CO will result in a less toxic compound.

The last pollutants the converter reduces are oxides of nitrogen (NO_x). Several different compounds (NO and NO₂) are included in the generic term NO_x. Unlike CO and HC, NO_x cannot be oxidized into a 'friendlier' chemical. Instead, it must be reduced. Simplified formulas for these reactions are $2\text{CO} + \text{NO}_x \rightarrow 2\text{CO}_2 + \text{N}_2$ and $\text{HC} + \text{NO} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{N}_2$. This reaction differs from the oxidation reaction in that it removes the oxygen molecules from NO_x to achieve nitrogen (N).

Author's Note: I must ask the indulgence of any chemist who reads this article. I have taken liberty in using a generic representation of the reactions that take place in the formulas above. Delving into the specific chemistry of these formulas is unnecessary for our purposes and could needlessly complicate our discussion.

For example, gasoline, the source for HC in the previous formulas, is actually composed of multiple compounds, including, but not limited to, sulfurs, butanes, aromatics, alkanes and alkynes. All of these chemicals affect the exhaust composition in different ways and therefore, complicate the chemical formulas. Methane is also present in gasoline, and few catalysts have any effect on residual methane. That is why FTP standards are for non-methane hydrocarbons (NMHC).

Catalytic Converters



A simple quick test for oxygen sensor heaters is to see how long it takes to begin to produce a voltage after starting the engine. This heater works well. Make sure the heater is being commanded on when performing this test.

Most early catalytic converters were simple oxidizers, using platinum or platinum/palladium. Secondary air injection systems on many of these systems also promoted oxidation. Some reduction occurred, but not enough to meet later and tighter NO_x standards. Rhodium was added to promote reduction, but this could only occur on the rich side of stoichiometry. Engines were designed to run close to stoichiometric, and the converter used a reduction brick in front and an oxidation brick in back, with secondary air injected inbetween. This design allowed oxidation and reduction to occur within a single converter.

The three-way converter (TWC) was developed to meet even tougher emission standards. This system utilized a tightly controlled fuel strategy and a converter that could promote oxidation as well as reduction. Most, but not all, TWC's contain palladium, platinum and rhodium. Feedback systems were developed to meet the needs of the TWC. Oxygen sensors are the basis for controlling fuel command that alters the gasses entering the converter.

What's It All For?

Contrary to popular belief, oxygen sensors *do not* control fuel for economy or power. The feedback system is used exclusively to control air/fuel mixture for optimum catalytic converter effectiveness. As the oxygen sensor (let's use a zirconium sensor for this discussion) voltage swings high, the TWC reduces NO_x; when the voltage swings low, the TWC oxidizes CO and HC. These two reactions reinforce each other and are dependent on the frequency of oxygen-sensor signal output swings.

Cerium is also added to converters for various reasons. The most important application is for temporary oxygen storage. Cerium catalyzes the adsorption of oxygen molecules, to assist in the oxidation of CO and HC a moment later. Some of this adsorption occurs as the result of NO_x reduction.

OBD-II Regulations

It seems only natural that if so much work has gone into the development of the catalytic converter, the OBD-II system should test it. By model year 2003, the story goes, OBD-II systems will monitor NO_x reduction effectiveness. Until then, manufacturers only have to test for hydrocarbon oxidation. Understand, the OBD-II system does not check pollutants exiting the exhaust system. The system is only able to *infer* the pollutant level. Sometimes people overlook this when diagnosing OBD-II codes.

Studies conducted in the 1980's indicated an interesting correlation between converter oxygen storage capacity and the effectiveness of hydrocarbon oxidation. Engineers discovered they could install an oxygen sensor downstream of the converter to measure the converter's oxygen storage ability. The signal from this sensor indirectly reflected how well the converter functioned. This test was only effective for measuring hydrocarbon reduction, of course. Catalyst oxygen storage capacity does not correlate with CO or NO_x reduction.

OBD-II regulations take this into account and prescribe the PCM must identify a converter that fails to effectively reduce hydrocarbons. The level of effectiveness required varies with the vehicle type, but most early systems could identify a converter that allowed 50 percent of the hydrocarbons through unoxidized.

Another ingredient thrown into the catalyst monitors mix is a strategy using the post-catalyst O₂ sensor for fuel control. The earliest reference this strategy is the late 1980's, so it is not a new concept. At least a few manufacturers have adopted this strategy, which means a faulty rear O₂ sensor can cause driveability problems. Many technicians have already encountered this condition.

Catalytic Monitors

O₂ Sensors

Using an oxygen sensor behind the converter can cause some dilemmas. Keeping the sensor active means keeping it hot. Oxygen sensor heaters have been around for some time, but they have never been as important as with a post-catalyst O₂ sensor. If the post-catalyst O₂ heater fails, it may never reach operating temperature. OBD-II requires monitoring of both pre- and post-catalyst O₂ sensor heaters.

Two systems are generally used: Time-to-activation with the heaters on and the engine off or actual measurement of current flow. Current flow is measured by operating the O₂ heater current via the PCM and testing current using electronic circuitry inside the PCM.

Catalytic Converters

Some strategies turn the heaters on after the car sits for a predetermined time, then monitor how long it takes for the sensor to produce a voltage. These are simplified examples, and you should consult a service manual for the make and model you are testing to determine the specific strategy.

OBD-II also requires testing the O₂ sensors for activity. Pre-catalyst O₂'s can be checked at any time but testing the post-catalyst O₂ is a little more difficult. The post-catalyst O₂ signal voltage changes according to converter activity, so it must be tested when the vehicle is first started and the converter is cold. This is described within the regulations.

Monitors

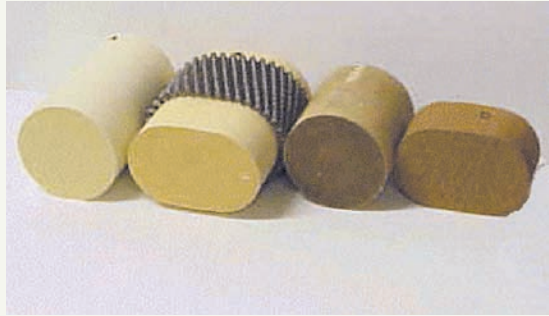
The basis for converter monitoring is in the response of the post-catalyst O₂ sensor as it relates in time to the front O₂ sensor. As the frequency of the rear O₂ approaches the frequency of the front O₂, it indicates a reduction in hydrocarbon oxidation effectiveness. Many different algorithms are used to determine this, and sometimes the actual determination is quite complex.

The volume of exhaust flowing through the converter has a major impact on post-catalyst O₂ activity. The post-catalyst O₂ is merely measuring oxygen storage capacity of the converter. This can change during various operating conditions, so converter testing must occur within certain parameters.

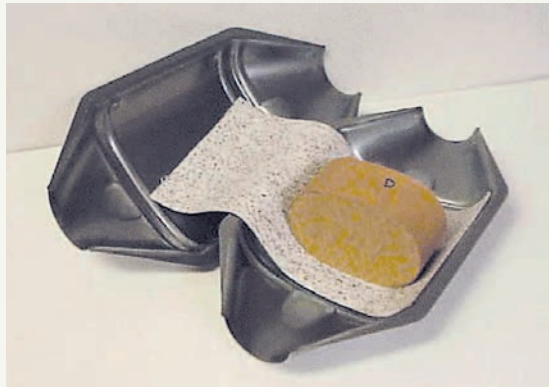
Different manufacturers utilize various conditions to monitor the converter for effectiveness. The test may be conducted at idle or at cruise, but it is generally conducted during low exhaust flow conditions. As flow increases, the frequency at which the oxygen molecules adsorb and release increases. This can cause the post-catalyst O₂ sensor to increase in frequency and result in a false failure code for the converter.

Parameters may change as the standards for finding faulty converters become tighter. Some regulations state the OBD-II monitor must identify 98 percent effectiveness. To achieve this tighter standard, some manufacturers install an oxygen sensor in the front section of the catalyst substrate. Installing an oxygen sensor farther forward for catalyst diagnostics allows the software to see a smaller surface area of the substrate. Focusing on this smaller area makes it easier to predict overall effectiveness.

Temperature is the critical factor for proper converter operation. If the catalytic converter is too cool, little or no oxidation/reduction occurs. Testing a converter under these conditions would result in a false failure, so engineers must incorporate catalyst temperature into the software.



Here are examples of different substrates for different applications. Notice the wire mesh on the second from the left. This is used to help deal with the expansion of the converter housing.



An intumescent mat is used to deal with different expansion rates. The stainless steel housing can expand 18 times the rate of the ceramic substrate.

Converters generally do not have a temperature sensor, so engineers develop a model to determine this parameter. If engine temperature is adequate, they can infer the converter temperature based on the airflow and engine load. This is calculated using the mass airflow sensor or manifold absolute pressure sensor. The calculation may take other factors into consideration, such as vehicle speed or air temperature, but they know whether the converter should be hot enough to run the catalyst monitor.

Unless there is a problem, it shouldn't be difficult to get a catalyst monitor to run to completion. Cruising at a steady speed between 40 and 60 mph, followed by an idle state should get almost any monitor to say READY. Likewise, if you are using O₂ sensor waveforms for diagnosis, whether they are from scan data or a DSO, make sure you are checking under the same conditions seen by the catalyst monitor. The catalyst monitor is usually one of the last monitors to run because it relies on other sensors and inferred temperature for accuracy.

Catalytic Converters

Modern OBD-II systems utilize two oxygen sensors to test for catalyst efficiency. The post-catalyst O₂ sensor should always have a lower frequency signal when the catalytic converter is functioning properly.



Catalytic Converter Codes

Several different OBD-II diagnostic codes are assigned to describe catalyst problems, including manufacturer-specific codes. The generic codes are represented by nine different numbers:

- P0420** Catalyst System Efficiency Below Threshold (Bank 1)
- P0421** Warm-up Catalyst Efficiency Below Threshold (Bank 1)
- P0422** Main Catalyst Efficiency Below Threshold (Bank 1)
- P0423** Heated Catalyst Efficiency Below Threshold (Bank 1)
- P0424** Heated Catalyst Temperature Below Threshold (Bank 1)
- P0430** Catalyst System Efficiency Below Threshold (Bank 2)
- P0431** Warm-up Catalyst Efficiency Below Threshold (Bank 2)
- P0432** Main Catalyst Efficiency Below Threshold (Bank 2)
- P0433** Heated Catalyst Efficiency Below Threshold (Bank 2)
- P0434** Heated Catalyst Temperature Below Threshold (Bank 2)

The codes may be confusing at first but realize that manufacturers use different converter configurations depending on specific engine needs. A Mazda 626, for example, may have a warm-up catalytic converter near the exhaust ports of the engine and a main converter downstream of that. The post-catalyst O₂ will be located after the warm-up converter and before the main converter. This configuration would set a P0421 code if the warm-up catalytic converter failed.

It is very important to identify the system before performing a diagnosis. Replacing one converter may solve a code P0420 on a vehicle; don't suppose it will always solve a P0421 on another. Don't get yourself into a situation where you replace the wrong converter!

Always check for related TSB's when dealing with early OBD-II converter codes. Some monitors were not properly designed, and the only fix is a software change. The 1996 and 1997 Mazda 626 2.0L is an example of a bad monitor. The fix for a P0421 on these is to reflash the PCM with the NGS tester, then recheck the converter.

Rechecking the converter is done by running the car until the converter is good and hot then measuring O₂ frequency at idle. Compare the pre- and post-catalyst frequency ratio. If it is closer than 2 to 1, the converter is defective. The actual procedure is in the TSB, so be sure consult it for more details before testing.

What's Next?

The future may hold some surprises for OBD-II technicians. One thing that is almost certain to happen is the addition of a catalytic converter temperature probe directly in the converter. This probe will provide a better overall picture of catalyst degradation. Temperature is also a better indicator of NO_x conversion and therefore may help predict NO_x reduction degradation.

By now you understand the complexity of the converter system and why it is critical to match components to original equipment design. A simple alteration that changes exhaust flow, O₂ location or exhaust temperature could result in false codes. Always do a visual inspection on any OBD-II vehicle when diagnosing MIL complaints. ■

—By Randy Bernklau