

Five-Gas Diagnostics

OR

Why do I need a Gas Analyzer?

By

Steve Zack

OTC Technical Trainer

Edited by

Chuck Eaves

J.A. Echols & Associates

Technical Specialist

Today, OBD II has been with us for over 10 years, and looks to be the automotive electronic system of choice for many years to come. Of course, eventually the OEM's, responding to ever-tightening government emission standards, will develop a new system. But for now, OBD II is alive and well, and is serving the motoring public and the service technician quite well.

A decade ago, no serious service technician would argue the usefulness of a sophisticated and accurate gas analyzer of some kind. The issues then were: can I afford a gas analyzer, and if so, do I really know how to use one? These factors haven't changed much, but OBD II has added another question: do I really need a gas analyzer for the OBDII stuff? Also, is there any real value to having a gas analyzer for the new hybrid vehicles?

The answer to the above questions above is, "absolutely!" The old saying hasn't changed one bit since the introduction of the internal combustion engine over a century ago: "what starts in the engine, comes out of the tail pipe". Or better put, "What enters the engine must be consumed to create energy, or it will exit the tailpipe unused". If you have been an automotive technician for very long dealing with driveability/emissions, you already know that reading trouble codes and changing parts can be a quick way to the poor house, or the jail house.

One tried and true way to verify scan tool readings is with direct testing, which is using a scope or multi-meter to follow-up your scan tool readings. While direct electrical testing is one of the best ways to verify scan testing, reading the exhaust gasses will tell the savvy technician almost all he needs to know, and quickly. Also, no expensive software upgrades are necessary year to year. Exhaust gases are generic. The same analysis applies to all gasoline engines, regardless of where the engine is used, how many cylinders it may have, etc. The acceptable levels of pollutants in the exhaust stream have been tightening up over the years, but the understanding of the various gas readings don't change.

Now for the fun part: just what are the pollutants coming out of the tail pipe, what do the various levels of each mean, and what do we do about them? Please read on. Give the following some study; it's not as mysterious as you may have been led to believe.

Internal combustion gasoline engines emit four pollutants: carbon monoxide (CO), an odorless, colorless, highly toxic gas; hydrocarbon (HC); sulfur dioxide (SO₂), and oxides of nitrogen (NO_x). HC is the unburned gasoline, and SO₂ is actually created by the catalytic converter. Remember the "rotten egg" smell of the earliest versions of the cat? That was sulfur, which was actually part of the gasoline compound until about 1977 when it was removed from gasoline.

A *perfectly* running gasoline engine will produce only CO₂, or carbon dioxide, and water vapor. Of course, internal combustion engines have never been perfect, and they get worse as they wear. The

auto technicians' challenge is to keep the engines in his care running as cleanly as possible for the benefit of maximum gas mileage, better performance, and a cleaner environment.

CO₂ is not a pollutant; it is a naturally occurring element of earth's atmosphere. The oceans of the world, earthquakes, and other phenomena produce huge amounts of CO₂ continually. By comparison, auto engines emit very little.

Also, all plant life on earth needs CO₂ to live, and more CO₂ means more plant life of all types. Trees are especially benefited by CO₂, and they give us much of the oxygen we breathe in return. Due to the tireless efforts of the U.S. State and National Parks systems and forest fire control, there are actually more hardwood and pines than ever in the United States. The vigorous replanting of harvested trees by the logging companies who realize the need to restore this essential lumber resource in order to stay in business is also an essential component to this process.

Man's activity on earth, especially in the CO₂ we generate, has been blamed on a phenomenon called "global warming". This publication is not intended to discuss the validity of this phenomenon, but scientists and climatologists are divided on whether human activity actually has much effect on the earth's temperature when viewed over the centuries.

How the Five Gasses are made:

The PCM controls the fuel (HC) delivery and ignition timing based on the amount of air being used, which the driver determines with his right foot. As the camshaft opens the intake valve, the low-pressure area formed in the cylinder above the falling piston pulls in a fresh charge of air, and the correct amount of fuel is added by the fuel injection system. The intake valve closes and the mixture of air and fuel is then compressed as the piston rises in the bore. The ignition spark causes the mixture to burn (oxidize) and expand, pushing the piston down in its bore with much energy, powering the vehicle. Contrary to popular wisdom, the fuel/air mixture doesn't explode; it burns rapidly. If an explosion does in fact occur, poor performance and even engine damage could occur.

A typical American gasoline blend will consist of about 35% by volume of various hydrocarbons (HC). OSHA's Material Safety Data Sheet (MSDS) lists several of these chemicals as hazardous: benzene (5% bv), toluene (up to 35% bv), naphthalene (1% bv), trimethylbenzene (up to 7% bv), and MTBE (up to 18% bv). Some sulphur components may be found in gasoline as contaminants, and must be removed in the refining process because these chemicals will damage the catalytic converter.

In the early 2000's, MTBE was removed from gasoline because of its' long lasting environmental impact on ground water. This danger had been long recognized, but MTBE was mandated as a replacement for tetraethyl lead as an octane booster. Of course, lead is very harmful to breathe, but MTBE was proven to be a strong contributor to cancer if ingested in drinking water, or through the skin. As a result of removing MTBE, parafin components such as alkylate, are added to replace the MTBE as an octane booster.

Air is made up of 21% oxygen, and about 78% nitrogen. The rest is made up of trace amounts of helium (He), argon (Ar), neon (Ne), hydrogen (H₂), water (H₂O), carbon dioxide (CO₂), and hydrocarbon (HC).

Oxygen consists of 2 molecules of O (O₂). The engine uses oxygen to create energy through an exchange of molecules, combining oxygen with either carbon (C) or hydrogen (H₂). This process is called oxidation, or burning. Nitrogen won't burn; it is a stable gas that also absorbs combustion heat.

As air and fuel enter the combustion chamber during the intake stroke, the valves close as the piston rises. The rising piston compresses the mixture, causing pressure to rise quickly. One result of this increasing pressure is that the air/fuel molecules are pressed together, and begin bouncing off each

other and the combustion chamber walls. As the molecules begin to absorb the heat being generated by all this motion, they expand and start to separate, becoming a vapor. The oxygen (O₂) molecules begin to break up into individual molecules, and the fuel (HC) will separate into individual hydrogen (H) and carbon (C) molecules. Due to the ever-increasing pressure and impacting molecules, molecular speed increases. The separated molecules are now lighter than when they were bonded together, and become very unstable, bouncing all over the place looking for something to bond to.

As the sparkplug ignites, the spark jumps the gap under pressure. This extreme electron pressure forces the molecules of O and O, and H and C toward a forced bond. With ignition, one O molecule will combine with two H molecules to create H₂O, and two O molecules will combine with one C molecule, creating CO₂. As oxidation increases, the newly created H₂O and CO₂ molecules create additional pressure. The engine captures all this pressure in the combustion chamber, creating usable power to move the vehicle. As the molecules continue bonding, the increasing pressure causes even more molecular speed. This activity is described as the burning the air/fuel mixture, and when the burning is completed, the exhaust gas is what is left to exit through the exhaust system.

By better understanding how the various components in exhaust gas are formed, you will be able to use the information from your gas analyzer to determine if the engine problem is mechanical or electrical.

So what are the three pollutants in the exhaust stream? They are NO_x, CO, and HC. As earlier stated, CO₂ and O₂ are naturally occurring elements in air, and are not harmful.

What is NO_x?

NO_x is one molecule of nitrogen and an unknown number ("X") of oxygen molecules. NO_x actually contains NO and NO₂. NO is colorless, and it makes up the bulk of NO_x. NO₂, however, is brown in color, and is a key ingredient in smog. Shop-quality gas analyzers that can read NO_x, like the OTC Performance Gas Module (attachment to the Genisys scan tool), cannot distinguish between NO and NO₂. It takes a very expensive lab-quality unit to yield such detail. But just being able to detect NO_x is sufficient, and many shop units cannot do even that.

NO_x is only created if combustion chamber temperatures exceed 2300 deg F. If this temperature is reached, (N₂) molecules will separate into individual (N) units. These individual (N) molecules will then combine with either one or two (O) molecules, forming the bond known as NO_x.

Obviously, the solution would be to keep combustion temps below 2300 deg F. Lowering compression ratios, as was done in the early 1970's, lowers the temps, but lowers mileage and performance, too. Octane levels in pump gasoline were also falling, from 100, to 87 or so, in an effort to lower NO_x levels. Large displacement V8 engines rated at a typical 350 hp or more, fell to a miserable 170-200hp from 1970 to 1972. They didn't make a lot of NO_x, but they had little of the old performance that made them so popular for so many years, and their gas mileage was unacceptable. The big V8's were all gone, except for in a few pickup trucks, by 1980.

In 1973, the EGR valve was introduced in most gasoline engine autos and trucks sold in America. These clever devices diluted the fresh mixture with already burned exhaust. Since this exhaust was relatively cool, combustion temps were moderated, and NO_x levels were lowered.

Another benefit of the EGR systems was the content of unburned HC in the exhaust being reused. This already rich mixture allowed for the leaning of the fresh air/fuel charge, improving mileage. Downstream of the engine, the improved 3 stage catalytic converters are doing a good job of converting NO_x into N₂ and CO₂, and oxidizing the unburned HC and CO, leaving H₂O and CO₂. These newer converters create much less exhaust restriction than the earlier units, further improving mileage and vehicle performance.

By the mid 80's, improvements in combustion chamber design, manufacturing methods, and much improved accuracy of timing and mixture brought on by fuel injection with electronic engine controls, have allowed compression ratios and ignition timing to be increased, improving performance to levels not seen in 15 years, while improving emissions and mileage at the same time.

What is CO?

Carbon monoxide is an odorless, colorless gas, a byproduct of combustion, and is highly toxic. CO is created as a result of insufficient oxygen in the fuel/air charge. This condition is known as a rich mixture. The fuel burn is incomplete, leaving one oxygen molecule to bond with one carbon molecule.

What is HC?

Unburned fuel in the exhaust mixture is called HC, and it is a toxicant. HC can be created because of a rich fuel mixture, which is a result of insufficient oxygen.

However, a lean condition will force the HC to recombine because of high cylinder pressure caused by too much air. Also, poor compression due to worn engine components can cause high HC because of the low cylinder pressure not being able to separate the HC.

Ignition system problems will cause high HC, because a poor spark won't create enough pressure to cause the H and C to combine with O. As the uncombined H and C, and O and O molecules strike the cylinder walls, they cool and condense back into HC.

As in the NOx example above, auto shop gas analyzers read the HC, or Hexane, value of the exhaust gas. To actually read individual H and C molecules, a very expensive gas chromatograph is necessary, and is way more than you'll ever need in your shop.

Understanding what the 5 gas readings mean to you:

Many component failures and system malfunctions will cause 5 gas abnormalities. For example, if the cooling system is using pure water, it will absorb combustion heat and reach its' boiling point rapidly, creating air pockets around the combustion chamber. These air pockets have no coolant in them, and will become hot spots, allowing combustion temperatures to rise too high. Just as bad is 100% antifreeze, which forms a blanket around the combustion chamber, keeping the heat in and also causing the combustion chamber temps to get too high.

Rust in the cooling system, poor circulation due to slipping belts, pulleys, or water pump impeller, or a defective thermostat all prevent the cooling system from keeping combustion chamber temps in check. These high temperatures will cause engine knock, which is a pre-ignition condition where the air fuel mixture is ignited not by the sparkplug, but by the heat of compression, like a diesel. The oxygen will prematurely consume the hydrogen, leaving insufficient O to burn the fuel. High HC is a result, and because the combustion is incomplete, high O2 will also show up. Low CO, low CO2, and high NOx will also be present.

If you are reading the firing line voltage with your OTC Solarity scope, you will see the line voltage exceed 12 Kv. Also, the flame front caused by pre-ignition, and the other one caused by spark ignition, will collide, creating the "ping" many of you are familiar with. This sound means your piston tops are taking a real beating. Sometimes, running a higher octane fuel will help, as octane is a measure of the fuel's resistance to pre-ignite.

A word about octane ratings. Contrary to popular opinion, fuel with an octane rating higher than the engine actually needs only wastes money. Remember, octane only indicates the "spark knock"

resistance of the fuel. If your vehicle pings lightly under acceleration, consider moving up to mid-range, or premium. If your vehicle knocks loudly under acceleration, your problems can probably be diagnosed with the proper use of a 5-gas analyzer.

Carbon build-up on the piston tops caused by prolonged over-rich running can heat the carbon to the point of being a pre-ignition source for the fuel air mixture, causing poor performance and potentially serious engine damage. Therefore, when repairing high CO conditions, always assume that carbon has formed on the piston tops.

Oil consumption (burning) will also leave heavy carbon deposits on the pistons, but oil consumption can cool the combustion chambers, too.

Carbon on the throat of the valves can absorb fuel before it's burned, leaning the mixture. In this case, your 5 gas analyzer should read high HC, high O₂, low CO, low CO₂, and high NO_x. The reason the high O₂ is that the carbon is soaking up the fuel, leaving a lean condition. Your Genisys scan tool will be reading a low O₂ sensor voltage (lean). Your Solarity engine scope will show a high secondary voltage, exceeding 12kv, and a possible appearance of a second spark firing line. The higher than normal firing voltage is a result of a mixture that won't readily ignite, indicating a lean condition.

Mechanical engine problems such as poor valve seating, or worn piston rings not only promote oil consumption and carbon build-up, but cause compression pressure to be low. This low pressure results in the O₂ and HC not effectively separating, limiting oxidation. Also, engine vacuum will probably be low, causing MAP voltage readings to be higher than normal, causing the PCM to increase injector pulse width, causing a rich condition. The 5 gas analyzer will read high HC, low O₂, high CO, low CO₂, and low NO_x.

Exhaust valve seats are not only to seal the exhaust valve properly, but also to cool the valve when it's resting on its' seat (closed). If the valve is not seating properly, the valve edge gets very hot, causing pre-ignition, which further heats the combustion chamber. Your 5 gas will read high HC, high O₂, low CO, low CO₂, and high NO_x. This is a lean condition, as you probably know by now.

Timing belts and chains should not be allowed to wear out before replacing them. If they get too loose, the camshaft events will be late, causing air to keep entering the cylinders longer than required. Therefore, compression pressure will be too high due to too much air in the chambers when the pistons reach TDC. The late valve timing causes the fuel/air mixture to burn too long, even after the exhaust valves have opened.

Late valve action will also throw the ignition timing off because the camshaft sensor will report in late to the computer compared to the crankshaft sensor. The computer may over-advance the timing to compensate, causing more pre-ignition and heat. Also, the late valve action will lower the vacuum, causing the MAP sensor voltage to be high, causing the computer to add more fuel. Your 5 gas will read high HC, low O₂, high CO, low CO₂, and low NO_x, a classic rich condition.

If you are tuning a vehicle with a conventional distributor, be careful not to advance the base timing too far. If you do, the ignition will occur early, causing the combustion pressure to spike as the compression stroke continues. This causes very high NO_x. Also, the early flame front will cause your 5 gas to read high HC, high O₂, low CO, and low CO₂, a classic lean mixture condition.

If your 5-gas analyzer were to read lean as described above, the EGR system could be the culprit. If the vehicle is equipped with an electronic valve, a full-function scan tool like the OTC Genisys should be able to cycle the valve, engine running or not, to check the valve's function. If you have a vacuum valve, or a Ford DPFE system, a MytiVac should be able to show you if the valve itself will open.

An EGR valve that is stuck closed, or a plugged EGR passage, will cause a very lean mixture, with readings like the example in the above paragraph. A road test will probably reveal engine pinging under load, poor gas mileage, and poor performance.

Rich gas readings can be caused by the MAP sensor out of calibration (low voltages), TPS out of adjustment (high voltages, causing the computer to over-compensate with long injector pulse widths), IAC closed, leaking injectors, low vacuum, or a very dirty air filter. Also, an evap purge system, introducing fuel vapors at the wrong time, or not at all, can cause a rich gas reading.

Leaking injectors, or a faulty fuel pressure regulator, can cause raw gas to seep into the crankcase. When the car starts and warms up, the gasoline vaporizes and is pulled into the combustion process through the pcv. The 5 gas will read high HC, as well as high CO. With a high CO reading, pull the pcv, or otherwise block the pcv system. With your OTC Performance Gas Analyzer operating in graph mode, look at the CO reading. If the CO falls 1 to 1.5%, change the engine oil, then find the reason for gasoline in the oil.

If your OTC Solarity scope shows low secondary voltage, suspect fouled plugs, or a weak coil. Low secondary voltage indicates a weak secondary pressure wave, causing poor oxidation of the fuel/air mixture. The 5 gas will indicate a rich mixture by showing high HC, high O₂, low CO, low CO₂, and low NO_x.

A secondary voltage reading in excess of 12kv can mean broken ignition wires, or worn plugs/cap/rotor. Your 5 gas will show high HC, high O₂, low CO, low CO₂, and higher than normal NO_x. This reading would normally indicate a rich mixture except for the high NO_x. The NO_x is explained by the high cylinder pressure induced by the high secondary kv reading.

Primary ignition current is charging system voltage, or 12 to 15 volts. The coil changes battery voltage into kv to light the fire. If primary voltage is weak due to battery problems, corroded battery cables or ground terminals, low charging system performance or other 12v problems, the secondary voltage will suffer. The effect will be to supply the combustion chamber with a weak pressure wave inhibiting oxidation. The 5 gas will show the classic rich mixture conditions in the paragraph before the one above.

Poor charging system performance is mentioned above, but a poor charging system will cause even more problems in the vehicle. If the charging system is insufficient, fuel pump performance may suffer. Also, the PCM itself may be affected, as well as the fuel injectors. Low charging voltage to these circuits will show the typical lean mixture readings on your 5 gas analyzer. If the ignition coil is operating with low voltage, the secondary voltage will be low, as explained earlier. Rich mixture readings will result.

Incorrect charging voltage can result from a faulty regulator diode. A bad diode can cause a charging spike, throwing reference voltages off. This in turn will alter sensor values altering injector pulse width and ignition timing resulting in a rich condition.

A leaking exhaust system, upstream of the O₂ sensors, will cause an erroneous lean reading. Your 5 gas will show high O₂, and possible low CO₂. A leaking exhaust system will prevent you from making any kind of reliable repair. Fix the exhaust leaks first.

Of course, this logic applies to any leaking component or system on the engine. The OTC 6521 or 6525 LeakMaster series of diagnostic smoke generators can pinpoint leaks in the evap system, intake and exhaust systems, gaskets of all kinds, leaking valves or rings, etc, etc, quicker and more reliably than almost any other method. The LeakMasters will pay for themselves quickly, just like our Performance Gas 5 gas analyzer, the OTC Solarity scope or scope module, and the incomparable OTC Genisys scan tool.

As you have seen, analyzing the 5 gas content of the engine exhaust will allow you to isolate the problem quickly, replace the faulty components or make adjustments as required, and get your customer back on the road. The most important thing to remember is that the PCM adjusts fuel and ignition timing based on air volume. Your 5 gas analyzer is your best attack on driveability complaints on all gasoline vehicles, old or new.

Use your OTC Performance Gas analyzer to point out problem areas. Then verify your findings with your OTC Genisys, Solarity scope, a compression guage, and a borescope. Get the problem fixed right the first time. If you follow this approach, your flat time will go down, your comebacks will decrease, and you will be more profitable. Isn't that what you want?

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