Getting the Most Out of Exhaust Gas Analyzers

by Bob Freudenberger

All the scopes and scan tools in the world won't tell you what's actually being spewed out of that tailpipe. Here's what a gas analyzer can do for you today.

It was long ago when we were doing drag racing photography that we first heard that there was such a thing as an air/fuel ratio meter.

Decades ago when we were involved in drag racing, we heard about a magical, mysterious device that would actually tell you the air/fuel ratio you were running. No more guesswork about jet sizes and metering rod settings, and no more coasting into the pits with engine off for a visual plug reading (we looked for a nice chocolate brown right at the edge of fouling). But we were never able to afford one, so we continued our previous experimental approach to assuring a nice, fat mix of about 12:1.

This early AFR meter sort of "guesses" at the HC level.

Not long thereafter, our state instituted emissions inspection. We were astounded to see on big analog meters the actual amounts of HC and CO our car was producing. Was there a miniature chemistry lab inside the machine? Actually, yes there was in the form of an infra-red bench, the operation of which we won't get into here beyond saying that it differentiates among the gases present on the basis of their absorption rates of infra-red wavelengths.

Before exhaust gas analysis, the only way you could tell how the air/fuel mixture was actually burning in the combustion chamber was to "read" the plugs, specifically the insulator nose. This one is way lean with a hint of detonation.

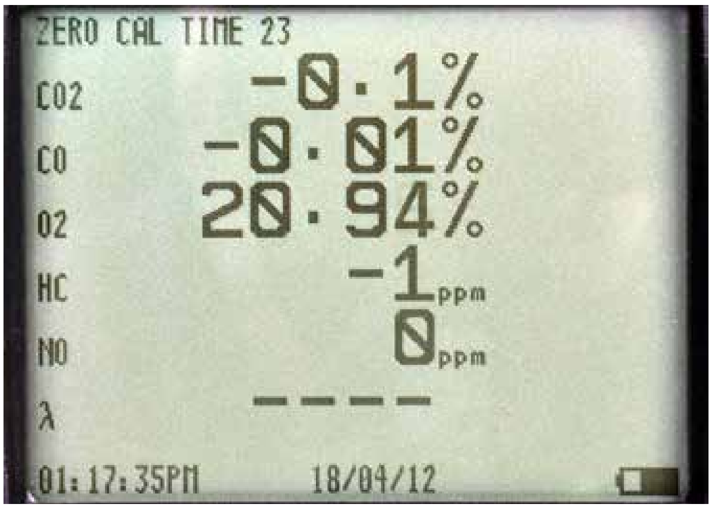
This analog unit from the late 1970s that was used for emissions inspections in some states could only tell you HC in parts per million, and CO as a percentage.

Multiple gases

In 1975, we as a society got acquainted with the catalytic converter, and all bets were off as far as two-gas was concerned. The catalyst did such a good job of cleaning up the exhaust that HC and CO readings taken at the tailpipe weren't as helpful for diagnosis as they had been. Some carmakers such as VW put in test taps upstream of the cat, but they weren't common.

So, analyzers soon evolved into the four-gas variety, which measures not only HC and CO, but also oxygen (02) and carbon dioxide (CO2). Being able to read these two additional gases, and taking note of the combination of all four, makes up for the effect of the catalyst. Also, CO2 is a great indicator of how efficiently an engine is burning up the air/fuel mixture.

This five-gas hand-held includes ingenious software that helps you make the most of its accurate readings (courtesy Kane).



The Kane display up close.

Today, most units are of the five-gas type, meaning they can measure NOx, too, something that had only been possible in the past with laboratory equipment. Opting for this feature when it first appeared was pricey -- from one manufacturer, for instance, it added about $1,400 back then -- but it was essential in areas that stuck to I/M 240 guidelines. It can also assist in troubleshooting lean conditions, EGR, and three-way cat inadequacies. You'll need either a dyno or a portable unit because this gas is only formed under load.

To test the amount of NOx an engine is generating, you'll either need an expensive and space-consuming dynamometer, or a portable or hand-held analyzer you can take with you on the road because that gas is only generated under load.

Of course, BAR 90 is the standard for accuracy, calibration, drift, and barometric correction, and a typical up-to-the-minute unit will tell you HC and NOx in ppm, and O2, CO and CO2 as percentages, with grams per mile conversions available. Other features may include air/fuel ratio, rpm, multiple snapshot mode, numerical or bar graph display, etc.

Angles and prep

You can look at exhaust analysis from either the emissions compliance or engine performance angle. In the former, you'll use the readings to make sure that car passes its smog test after you send it out, and in the latter you'll use them in conjunction with all your other troubleshooting equipment and know-how to zero in on the reason for a driveability complaint.

Before you jump into gas analysis, there are a few things to bear in mind. First, the analyzer manufacturers, along with everybody else in the business of automotive diagnosis, stress checking the basics before engaging any heavy-duty troubleshooting artillery, and commonly give a list of items from the air filter and crankcase contamination to spark plugs.

Years ago, a passage from one of the major analyzer maker's user's manual made us chuckle:

"Performing a diagnosis from the exhaust gas sample can be very difficult on an engine that has any combination of the following:

- catalytic converter
- computer control system with an oxygen sensor and fuel injection
- air management system
- exhaust gas recirculation system
- canister purge system
- electronic spark timing, electronic spark control or both
- PCV system
- distributorless ignition"

Any vehicle that doesn't have most of those systems should be in a museum -- PCV went national in '63, evap in '71, and EGR showed up in '72.

But even back then you could get meaningful readings if you did a little "pre-conditioning," which included such things as removing the air injection pump belt or clamping its outlet hose, plugging the gulp valve, or making sure the computerized engine management system is in closed loop (as you may remember, early versions of electronic engine management systems could drop out of this mode after idling or immediately upon restart and would tend to go rich, something that pretty much never happens with late models).

Now, with super-accurate analyzers and ingenious software this is no longer an issue. You'll get true, helpful results.

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Think about it for a minute, and you'll realize that there are actually eleven things present in the exhaust of an internal combustion engine:

- O_2
- CO
- CO_2
- HC
- NO_x (including nitric oxide and nitrogen dioxide)
- H_2O
- SO_2
- N_2
- H_2
- soot/particulates
- heat

From a diagnostic standpoint, of course, we're only interested in oxygen, carbon monoxide, carbon dioxide, hydrocarbons, and oxides of nitrogen.

The oxygen reading represents the amount of O_2 that's left over after the big blaze. To put it another way, it's the result of combustion with an excess of oxygen present. Some authorities suggest that you pay attention to this before anything else.

A low O_2 level points to a rich mix (the engine may be running great, but where are efficiency and emissions?). A high reading indicates an excessively lean condition -- in fact, it's an especially good lean indicator. For example, a dramatic rise may be caused by lean misfiring, which you might attribute to something like an inoperative injector, a vacuum leak, or a perforated duct between the MAF and the throttle. A typical engine will give an O_2 reading of between 0.5% and 4%. Above 4% means lean misfire.

CO is bad juju to breathe, and is produced by incomplete combustion -- the air/fuel charge is being ignited, but isn't burning properly or entirely. Or, to contrast it with O_2, it's the result of combustion with an excess of fuel present. In most cases, this is due to fuel system troubles that make the engine run rich, but intake air restrictions could affect it, too. Typically, CO decreases as the a/f ratio approaches 15:1 and stays low with even leaner blends. So, it's a good indicator of richness, but a poor indicator of leanness.

It's important to note that some combustion is required or CO simply can't be created. So, you won't see a high CO reading if there's no spark. Along with HC, CO will rise with a rich mixture.

Oxygen and carbon monoxide readings should be viewed as a pair. If they're nearly equal, the engine's running pretty close to stoichiometry. A rich mix will give you low O_2 and high CO, whereas lean will display high O_2 and low CO. Think of them as veering off from each other as the air/fuel ratio goes away from the sacred 14.66:1.

The global warming question aside, CO_2 is harmless. Its presence in exhaust means combustion is complete. In fact, as combustion efficiency rises, so does the carbon dioxide reading. So, this is valuable information on how well the engine's running. The volume of CO_2 peaks at about 15:1, and decreases if this swings either way.
The desired range is commonly between 12% and 15%. Generally, an engine is operating most efficiently when CO_2 is at its highest. The most common causes of low CO_2 are misfiring and an improper mixture.

Hydrocarbon emissions are just what they sound like: unburned fuel (and maybe a little motor oil) being pumped raw into the exhaust system. Misfiring is a likely culprit, and that can come from lack of ignition or a mechanical problem (a burned valve, perhaps?). Another possibility is a mixture that's too lean to catch fire either because of a fuel system malfunction or a vacuum leak. If a big HC number isn't from a miss, it's probably due to a rich mix (in previous decades, we'd look for heavy floats).

This can be a little tricky because a/f ratios that are either too lean or too rich can cause hydrocarbons to soar. We should also mention that the lowest HC emissions occur at about a ratio of about 16:1 (providing it doesn't cause a lean miss), and that production of this gas depends heavily upon combustion chamber shape, quench area, swirl and tumble, so there's a big variation among engines.

Hard case

NO_x has been a tough one. It forms when nitrogen (78% of the air we all breathe) combines with oxygen (21% of the atmosphere), which can happen ONLY at very high combustion temperatures. The trouble was, many of the things that were initially done to cut HC and CO involved dramatically increasing the heat inside those cylinders, which created plenty of NO_x. Fortunately, it was found that only the peak temps (over 2,500 deg. F.!) produced this smog-promoting gas, not the long, hot burn that oxidized those other two pollutants. Introducing EGR knocked the top off the temperature curve, thus putting NO_x within bounds. Of course, now we have computerized engine management systems and three-way cats to further diminish it.

What will a high NO_x reading tell you? Well, as far as a/f ratio is concerned, you'll get the largest volume of this nasty stuff at 18:1, and going from 16:1 to 15:1 will cut it by 25%. So, other things being equal, big NO_x means lean mix. Of course, there are other factors that can have a profound effect on this reading, especially clogged EGR passages or an inoperative valve, or a cat that isn't doing its reduction job. Also, you'll see big spikes in NO_x whenever detonation occurs. We'd better add an interesting -- and crucial -- point: Moisture-laden air can lower NO_x output by as much as 30%, so keep the weather in mind.

Unite and conquer

As you know if you've been following the ads in trade mags like ***Motor Service***, there's big news on the equipment front. Gas analysis by itself is a great diagnostic aid, but it really gets powerful when it comes combined with a scan tool, DMM, lab scope, or even a PC.

While we're not going to try to catalogue every feature of every make and combo out there, we can tell you that we tried some neat software from a major equipment maker that interfaces (pardon the buzz word) a five-gas bench with your PC. Not only does it give you line graph, bar graph, and numerical displays, it also keeps detailed customer records and files of previous tests. It was easy to use and the color-coded line graphs looked, well, cool up on our big monitor.

By the way . . .

The following miscellaneous points on the use of infrared exhaust analyzers should help keep you out of trouble:

-Up to 30% of engine air flow at idle is coming through the PCV system. If the CO reading changes more than 1.5% with the PCV valve disconnected, leave it out for the test, then change the oil before the lifters and bearings die from diluted oil.

Did you ever realize that up to 30% of flow into the intake manifold at idle is from PCV? So, if the crankcase oil is contaminated with gasoline, you'll see false combustion readings on your exhaust analyzer.

- If you're using a dyno, remember that the load has to be just right to get true NOx readings. If it's too heavy, you might go into enrichment and cool things off.

- Trying to measure NOx while torquing the car up on its brakes won't only put you in enrichment, it'll often keep the EGR valve from opening.

- The vehicle's emissions decal may give specific instructions for infra-red testing. For instance, it may be necessary to disconnect the charcoal canister purge hose.

- Park the car in a well-ventilated area. Exhaust in the ambient air will affect the readings besides being a hazard and a nuisance in the work place.

- Both the analyzer and the vehicle's engine should be thoroughly warmed up before testing. In the case of the engine, you must be sure that the cold enrichment and fast idle functions are no longer in operation, and that the oxygen sensor is hot enough to produce voltage.

- Always test at more than one rpm level -- idle readings alone won't tell the whole story. To illustrate, both HC and CO should be lower at 2,500 rpm than at idle. If the readings are the same or higher, a problem exists. High HC at 2,500 rpm may mean there's a high speed ignition miss, or perhaps a lean misfire. If you had checked emissions at idle only, you wouldn't have known this.

- Don't forget that gas analyzers are also useful in troubleshooting no-starts, combustion-to-cooling system leaks, etc.

Bob Freudenberger *has been an automotive tech writer and magazine and book editor for four decades. He's had thousands of magazine articles, numerous video training programs, and several books published, and is the author of The Encyclopedia of Auto Technology & Service, and The Repair Library. He was an editor for Hearst's MOTOR Books, the editor of Speed Shop magazine, and the editorial director of Motor Service and Auto & Truck International, Tech Drive (BMW), Tech Connect (VW), Nissan TechNews, and The End Wrench (Subaru). He's also written many "Saturday Mechanic" features for Popular Mechanics.*

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Bob is hands-on . He has his own shop where he not only fixes cars, but also researches service issues, tools, and equipment.