Technical Support Note

Title: Using the Oxygen and CO2 gas levels to detect air dilution
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Overview:

The purpose of this document is to provide general guidelines regarding air dilution effects, and how being able to measure exhaust O2 and CO2 detects and corrects air dilution so that accurate exhaust gas levels can be measured at the tailpipe.

Exhaust Gases – Principle of Combustion:

The purpose of the engine is to use the oxygen in ambient air (about 21%) to oxidize the hydrogen and carbon atoms in the fuel, producing heat as a result, and then to use this heat to create mechanical power. To do this, the engine intakes ambient air, mixes it with the correct ratio of fuel, intakes it into the cylinder, ignites it, and uses the heated expanding gas to create power. The air/fuel mix is balanced by the carburetor or fuel injection system so that there should be just enough oxygen in the incoming air to burn all of the fuel that is being delivered. A perfectly balanced air/fuel mixture is called Stoichiometric – and spark-ignited engines seek to maintain air fuel mixtures close to stoichiometric throughout the operating range of rpm and power settings. This principle can be used to detect air dilution.

Delivering a good exhaust gas sample to the analyzer– the primary problem:

Often it is difficult to get a good exhaust gas sample into the analyzer for analysis – due to exhaust gas pulsations, insufficient probe insertion, low exhaust gas volume, or an extraneous air leak. When this happens, the real exhaust gas is mixed with outside air and the resulting gas mix is delivered to the analyzer. However, the levels of O2 and CO2 in the delivered gas often can be used to determine the relative amounts of exhaust gas to ambient air in the gas sample. The complete oxidation of hydrogen in the fuel produces H2O (water) and the complete oxidation of carbon produces CO2 (carbon dioxide) – so these are generally referred to as the ‘natural’ products of combustion. Most of the water vapor in the exhaust condenses into liquid water and the rest remains a vapor and is not measured by the gas analyzer. The Carbon Dioxide remains a gas and is measured by the analyzer, so it is a good indicator of combustion. In addition, ambient air contains 21% oxygen in it, while exhaust contains very little – less than 0.5%. This

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difference (exhaust contains high levels of CO2, and low levels of O2 – ambient air contains low levels of CO2 and high levels of O2) can be used to detect and even correct air dilution of exhaust gas.

Single and 2-Gas Analyzers – Miss Air Dilution:

Single and 2-Gas Analyzers measure only CO or CO and HC. That is, they measure only the fuel-related products of incomplete combustion – the 'bad' gases in the exhaust gas. Unfortunately, this means they do not have the capability to see the main product of combustion (CO2) or how much O2 is in the delivered gas stream. So – these gas analyzers may be reporting either undiluted or diluted CO or CO and HC – and there is no way to tell the difference.

4 and 5-Gas Analyzers – Detect Air Dilution:

Ambient air has about 20.6% O2 and 0.1% CO2 in it, while exhaust gas has 1.0% or less O2 and 12.0% (LPG) or 15.0% (Gasoline) CO2 in it. This extreme difference in the relative amounts of O2 and CO2 in exhaust gas vs ambient air can be used to tell how much of the gas being delivered to the analyzer is true exhaust gas and how much is ambient air. Once these relative ratios are determined, the exhaust sampling method can be improved by probe insertion, gas volume increase, or reduction of the effects of gas pulsation, or if not correctable at the source, the gas readings can be mathematically corrected for air dilution.

These options simply are not possible unless Oxygen and CO2 are measured. This is one of the reasons that tailpipe exhaust gas readings can be made much more accurate by using a 4 or 5 gas analyzer.

How to use the O2 and CO2 Readings to estimate air dilution:

Every 1.0% increase in O2 above the expected value in exhaust gas is an indication of 5% air dilution of the exhaust gas. This is because we know that there is 20.6% O2 in ambient air – and this value is quite constant. So, for example, if the analyzer is indicating 4.5% O2, and you are expecting to see 0.5% O2, then you have 4.0% excess Oxygen – an indication that the gas sample is about 20% ambient air, and thus only 80% exhaust gas. The air dilution effect on the CO2 reading is that you would see only 80% of the expected 12.0% CO2 in LPG fueled or 15.0% CO2 for gasoline fueled vehicles, meaning about 10.0% CO2 for LPG, and 12.0% CO2 for gasoline. If this is close to what the reading is on the analyzer CO2 display, you pretty well have confirmed that you do indeed have 20% air dilution of the exhaust gas.

Using both O2 and CO2 together allows you enough information to be confident of the magnitude of air dilution that truly exists.

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Knowing that you have 20% air dilution means that the CO, HC, and NO readings will only be 80% of their actual value too (any gas but O2 will be diluted by 20%) – so you either have to reduce the amount of air dilution in the gas sample or mathematically correct the non-O2 gas readings by dividing them by the exhaust gas dilution, 0.80 in the case above. This will mathematically increase the measured gas readings to allow you to get back to what they would be in undiluted exhaust.

Correcting Sources of Air Dilution – Look at O2 and then CO+CO2:

When the probe is first inserted in the exhaust pipe (engine running), you should expect to see the indicated O2 reading go down from 20.6% to 1.0% or less within about 10 seconds. If the O2 level does not go down below 1.0% or 2.0% – but stabilizes at a higher than expected reading, this is an indication that air dilution exists.

The O2 readings can be reduced by changing the probe insertion length, position, or partially blocking the exhaust - or by increasing the throttle setting to increase the gas flow.

As stated earlier, undiluted exhaust has about 0.5% O2 in it, so you should strive for that target – although less than 2.0% O2 is generally acceptable.

Once you have reduced the O2 readings to less than 2.0%, you should also confirm that the sum of the CO and CO2 readings is close to 15% for Gasoline and 12% for LPG. If they are, you can be confident that you are measuring exhaust gas, and the gas readings you are getting are accurate.

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