White Paper

Title: Comparison of Chemical Sensor and NDIR Technologies for Measuring CO in Vehicle Exhaust
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Created by: R. Schrader
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Carbon Monoxide in Exhaust - Overview:

Carbon Monoxide is a toxic gas produced by incomplete oxidation of hydrocarbon fuels and is measured commonly in exhaust gases for three purposes:

1. To make sure it is low enough in the exhaust that once it gets diluted by ambient air, the resulting breathing air still meets OSHA standards (50 ppm Time Weighted Average for 8 hours exposure) for indoor-operated equipment – like LPG fueled forklifts, sweepers, etc.
2. To make sure it is high enough to ensure that performance-tuned equipment is rich enough that they never get into a lean-misfire mode.
3. To make sure the engine is well tuned and that emission control equipment is working properly and the vehicle meets or exceeds EPA regulations.

The basics of Measurement – Chemical Sensors vs Infrared Technology:

Chemical Sensor Carbon Monoxide Measurement:

Chemical sensors have been used for toxic gas measurement, including CO, in personnel safety monitors for many years. They are relatively simple devices that react to the presence of small amounts of CO in ambient air and produce a small current which is an analog of the ambient CO concentration. They are zero stable – as no current output will be produced unless CO is present.

<u>Span Instability:</u>

However, as the output is produced by a chemical reaction to CO gas, their gas sensitivity is intrinsically temperature and time unstable. Typically, chemical sensors are specified by their manufacturers as having about 5% span sensitivity increase for every 10 Deg C temperature change, and an additional 2% sensitivity reduction per month from the date of manufacture – until they reach their lifetimes of 12-24 months. Because of this instability, their accuracy can only be assured by calibrating them using a standard

Bridge Analyzers, Inc. (510) 337-1605 office
PO Box 39325 (216) 274-9262 fax
Solon, Ohio 44139 USA support@bridgeanalyzers.com

calibration gas. This effect is referred to as span instability – and is typically the case with chemical sensors. – Zero Stable, but Span Unstable. That the user should expect frequent (monthly or weekly) gas calibration of gas analyzers using a chemical sensor to make the CO gas measurement. Additionally, this will not assure that the instrument will remain stable when there is a temperature change.

Hydrogen Sensitivity:

Due to the fact that the chemical sensor that measures CO is actually responsive to the H+ ion, it is also sensitive to any Hydrogen gas in the gas mix being measured. Unless compensated by a separate electrode, the standard CO sensor will be about 60% as sensitive to H2 as to CO. (100 ppm H2 will read as 60 ppm CO). Exhaust gas has about 1/3 as much Hydrogen as Carbon Mondoxide, so the normal engine out gas will read about 20% high Carbon Monoxide. This is a cross-gas interference – which means that it cannot be calibrated out of the instrument. A properly calibrated analyzer (calibrated on hydrogen-free gas) will read hydrogen in the measured gas mix as Carbon Monoxide – at about 60% of its Carbon Monoxide sensitivity. The only way to correct this effect is to calibrate for the combined effects on a gas mix containing Hydrogen in the correct ratio to Carbon Monoxide with a balance of Nitrogen – and compensate the sensor cross-gas specific response by means of a separate electrode on the sensor provided for that correction and using two calibration gases, one containing Carbon Monoxide and Nitrogen, and one containing Hydrogen and Nitrogen.

This is a non-specific response. The sensor main output has no way of knowing whether the H+ ions are being produced by Carbon Monoxide in its normal chemical reaction, or by disassociation of hydrogen gas in the electrolyte.

Sensor Life:

Chemical Sensors 'wear out' with time. They not only require frequent calibration, but gradually degrade in sensitivity until they are unusable within 24 months – and will require replacement at or before that time.

NDIR (Infrared) Carbon Monoxide Measurement:

Because CO is a relatively strong infrared absorbing gas, NDIR is a good choice for CO measurement. NDIR (Infrared) technology has been the technology of choice for exhaust gas analyzers, due to its superior stability and longevity, as infrared technology does no require re-calibration, and has no consumable parts. In addition, other gases in exhaust have little or no effect on the gas being measured, due to the intrinsic nature of infrared gas analysis, being very specific to the gas molecule.

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<u>CO2 Cross Gas Interference:</u>

There is a small, but measurable cross sensitivity between CO and CO_2 due to overlap of their separate and specific infrared spectra. CO_2 produces infrared energy absorption within the CO spectra – and this can cause artificially high CO readings in a high CO_2 gas environment unless corrected for in the instrument. This effect is well understood, however, and is normally characterized during calibration with separate and combined gas mixes – and since CO_2 is separately measured by its own detector and is not affected by CO, a cross-gas correction is relatively easily obtained from the separate CO_2 measurement and applied to the CO measurement made at the same time.

The basics of Measurement – Multiple Gas Measurement vs Single Gas Measurement:

In addition, there is an issue of the need to measure other gases than CO – even though CO is the most important gas. In order to verify that the tailpipe measurement of CO is accurate, two things need to be done:

1. The CO has to be measured with accuracy and stability. Infrared is superior to chemical sensors in this regard, as discussed above.
2. A good sample of exhaust gas has to be delivered to the analyzer for measurement. Due to the pulsating nature of exhaust, there is a significant opportunity for air-dilution of the exhaust gas sample that finally reaches the analyzer.

This second factor is totally independent of the stability and accuracy of the measurement technology used. The analyzer can only measure what it is given, and if the exhaust gas is diluted by ambient air, the CO (and other exhaust gas) readings will go down. We have commonly seen 50% or more air dilution of tailpipe exhaust levels due to this effect – resulting in a CO measuring ½ or less of its true value. This makes the forklift technician think that the forklift is in tune when it is in fact emitting high levels of CO, and makes the performance tuner tune the engine incorrectly rich to make up for the dilution.

The only way to know if there is air dilution is to measure the most common gas in tailpipe exhaust (CO_2) and the most common measurable gas in air (O_2). True exhaust has very little O_2 in it, but 12% to 15% CO_2, depending on the fuel. Air has little or no CO_2 in it (less than 0.05%) and 20.6% O_2. This great difference in the two gases means that an analyzer that measures CO_2 and O_2 can be used to ‘qualify’ the gas being delivered as exhaust gas. In fact, if these two gases are NOT measured – there is really no way to tell if there is air dilution of the gas being measured.

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Analyzers which use NDIR for CO and other critical exhaust gases, and a chemical sensor for O_2 measurement have become the norm for exhaust gas analysis due to the reasons above. The ready availability of ambient air to stabilize the O_2 channels has made these very practical instruments in this application. This is primarily due to the choice of gas measurement technologies which take advantage of the characteristics of room air to both zero-stabilize the NDIR gas measurement channels, and to span-stabilize the chemical sensor O_2 measurement channel.

Total Benefits to 4-Gas Measurement vs Single Gas or 2-Gas Measurement:

Once the decision has been made to use a 4-gas analyzer with a CO_2 and O_2 measurement channel the user automatically gets the following benefits:

1. The ability to verify the level of air dilution and correct it or compensate for it as required. Correction is usually done by improvement in probe placement or type. (See TSN 22 - Hard Seal Exhaust Port) Compensation is done by mathematical correction of the tailpipe gas readings. (See TSN 17- Tailpipe Exhaust Gas Air Dilution & 4 Gas Math)
2. Real-time Lambda and AFR. (See White Paper No.10 - Lambda & AFR Calculation Capability in 4 and 5 Gas EGA)
3. Real Time Combustion Efficiency. (See and White Paper No.12- CE Calculation and White Paper No.27 - Lambda and CE for Vehicle Diagnostics

For the professional, having a gas analyzer that is stable and accurate, and does the total job that needs to be done to facilitate tuning is a great asset – making tuning by exhaust gas much more dependable than other methods.

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