White Paper

Title: Comparison of Chemical Sensor and NDIR Technologies
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Chemical Sensor vs NDIR - Overview:

There are two primary methods for measuring combustion gases – a multi-gas combination NDIR – Chemical Sensor analyzer, or a Chemical Sensor analyzer. Comparison of the two technologies is relatively straightforward once the basic principles of measurement are understood, as the differences between instrument accuracy, stability, and cost of ownership springs from the underlying measurement principles.

NDIR Technology:

NDIR stands for Non Dispersive InfraRed – and means that gas is measured through a non-destructive method of measuring how much infrared energy is absorbed at the specific resonant molecular frequencies for specific gases. This method makes use of the characteristic that the degree to which infrared energy is absorbed is a function of the number of molecules in the optical path (a special case of Beers Law) – and that this is only effected by the path length and molecular density. As the optical path length in an instrument is fixed by the design, once an instrument is characterized using real calibration gas mixes, its response to gas molecular density is known and invariant.

This is by far the most common method to measure gases with strong infrared signatures, such as Carbon Monoxide, Carbon Dioxide, and Hydro-Carbons – with literally 100,000's unit installed base. It has been the standard measurement method specified for US and International internal combustion engine exhaust gas emissions control system qualification and inspection methods due to its reliability, stability, and low cost.

However, this technology provides the strongest infrared signal when there is no gas of interest absorbing any infrared energy. NDIR measures the relative LOSS of infrared energy due to the infrared absorption of the gas of interest, so it must know what the total infrared energy is at the time of measurement. To do this, it must periodically purge the optics of gas of interest and obtain a reference infrared energy level. This requirement to periodically 'Zero' to obtain a current reference infrared energy level it is known as Zero Unstable, but Span Stable technology. Fortunately, a Zero reference gas is generally readily available, as ambient air has trivial levels of the constituents of internal combustion exhaust gas and is readily accessible. Once this energy reference is obtained, the relationship between the degree of energy loss and molecular density of the gas being measured is very stable – and NDIR have proven to be exhibit very stable measurement accuracy over years of use.

Automotive exhaust gas analyzers have measured CO, CO2 and HC gases using NDIR technology for more than 25 years – with a high reputation for accuracy, reliability, and low cost of ownership. Continual evolvement of NDIR gas analyzer technology has kept pace with the increased requirements for accuracy and stability due to the marked decrease in CO, HC, and NO levels – especially in catalytic converter equipped vehicles – and additional improvements in analyzer size and power have facilitated their application to non-road vehicles. Modern battery powered portable and hand-held exhaust gas analyzers are currently in common use for equipment certification and maintenance.

Chemical Sensor Technology:

Chemical Sensors are available for measuring chemically reactive and toxic gases, such as CO, S2O, Ammonia, and NO. These chemical sensors require little or no power, and produce a small electrical current which is a linear function of the gas measured – so they are relatively simple to implement in analyzers and exhibit a very Zero-Stable response. If there is no gas of interest present, no electrical current is generated, and the analyzer output remains at zero.

However, due to the fact the chemical sensor output is developed from a chemical reaction, the sensor is subject to environmental effects (chemical reaction rates double with every 10 Deg C temperature change) and sensor aging. Typically, chemical reaction rates double with every 10 Deg C temperature change, and natural aging causes a reduction in chemical sensitivity of around 10% per year. Both of these factors cause chemical sensors to be Span Unstable – so while they are Zero Stable – the electrical current output can vary significantly with time and environment when exposed to the same test gas. Due to these factors, chemical sensor based analyzers have found most common application in personnel safety monitoring for toxic gases – where the no gas is the expected condition, and the absolute level of gas present is less important than the fact that it exists at all.. For exhaust gas analysis, the chemical sensor technology has to be stabilized by pre and post calibration methods using calibration gases themselves.

Summary:

NDIR is intrinsically Zero Unstable and Span Stable. It does not experience long-term span drift, but has to be stabilized with periodic Zero-ing on gas not containing the measured gases.

Chemical sensors are intrinsically Zero Stable and Span Unstable. They experience long and short term span drift, but little Zero drift and have to be stabilized by periodic calibration on test gas.

Flue Gas Analyzers:

Due to the fact that flue gas is generally highly diluted (typical corrections to 15% O2 , equivalent to a mixture of 25% exhaust, 75% air is made) and is very lean-burn external combustion (where large amounts of excess air are delivered to the burner) – there is a low level of HC (not measureable with chemical sensor technology), the CO and NO levels are diluted and relatively low, and CO2 is generally calculated from the CO and O2 values using fuel constants. This means that two constituents of the combustion gas are generally not measured with chemical sensor based analyzers - HC (the fuel itself) and CO2 (one of the primary products of combustion). Chemical sensors simply cannot be used to measure either of these gases.

In this application, chemical sensor-based instrumentation has long been used to make periodic survey measurements – although they need to be calibrated before use, and do not measure all the gases. They are, however, viewed as sufficient to make the gas measurements needed to generally qualify the equipment.

Exhaust Gas Analyzers:

Exhaust gas from internal combustion engines, by contrast, is highly concentrated. In this gas, the constituent concentrations can typically be quite large, with very low levels of O2 and NO. The most common way to measure exhaust gas from internal combustion engines is to use a multiple gas analyzer using NDIR for those gases with a strong infrared signature (CO/ CO2 / HC) and chemical sensors for O2 and NO, chemically reactive gases that do not have a strong infrared signature. Because CO2 and HC are non-reactive, they cannot be measured by chemical sensor techniques – and are either estimated or ignored in a chemical sensor analyzer. In order to determine AFR and Combustion Efficiency (two very valuable engine operation parameters) the true value of CO2 and HC must be known. To date, the only analyzer that can measure all 5 gases individually and specifically in a concentrated gas stream is an analyzer that uses a combination of NDIR and Chemical Sensor technologies.

These analyzers are stabilized by periodically zeroing on ambient air, which serves the purpose of zero-stabilizing the NDIR measurement channels, while span-stabilizing the O2 chemical sensor (ambient air has 20.6% O2 in it and is used to recalibrate the O2 sensor during the NDIR Zero process). The only sensor which is not stabilized is the chemical sensor measuring NO, which must be periodically stabilized by calibration on a gas containing NO. In this way, measurement technologies are chosen that make the best trade-off for long-term stability vs cost.

Calibration Considerations:

There is nothing in the NDIR based exhaust gas analyzer which necessitates frequent gas calibration – even the most unstable analytical element (the NO chemical sensor) degrades at a fairly slow rate – about 10% per year.

However, it must be said that the only way to verify analyzer accuracy is to flow certified gas through it under the conditions of use. It is recommended that this method be used if there is any uncertainty about gas analyzer accuracy.

A Convenient Solution – BAR-97 Certified Gas Blends:

Small, disposable steel calibration gas cylinders containing a mix of the gases being measured are readily available for periodic calibration and accuracy checking. These disposable cylinders are specified for California BAR-97 (or the equivalent) emission testing program, and are available in two blends – BAR-97 High Span Gas, and BAR-97 Low Span Gas.

The constituent mixes are given below:

Gas Contents in BAR-97 Certified Calibration Gas Blends:

Nominal (target) gas values:

Gas	**Bar 97 High** **(Calibration Gas)**	**Bar 97 Low** **(Accuracy Checking Gas**	Units of Measure
(Propane) HC	**3200**	**200**	ppm
CO	**8.00**	**0.50**	Percent
CO2	**12.00**	**6.00**	Percent
NO	**3000**	**300**	ppm
O2	**0**	**0**	Percent

Note: Gas blending of BAR Certified gas mixtures is required to be accurate within +/-2% relative to gas value. The actual (within blending accuracy) value of each gas contained in each cylinder is given on a ‘Tag’ affixed to each cylinder. The ‘Tag’ value (not the values above) is what should be used for gas analyzer calibration.

Bridge does NOT recommend calibrating the analyzer on ‘Low’ gas mixes due to their proximity to the Zero point. The ‘Low’ gas readings for NDIR gases are predominantly affected by the accuracy of the Zero, not the gas calibration of the instrument.

Bridge can supply either or both of the BAR-97 gas blends above, as well as a regulator/adapter that interfaces between the calibration gas cylinder and the analyzer. This makes for convenient field-certification of analyzer accuracy if necessary.