



# White Paper

Title: NDIR Technology Overview, Compliance, and Comparison to Other Generally Available Gas Measurement Technologies

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## Overview:

Bridge Exhaust Gas Analyzers use two measurement methods for exhaust gas analysis: NDIR for CO, CO<sub>2</sub>, and Hydrocarbons, and Chemical Sensors for O<sub>2</sub> and NO. These technologies are approved for use in exhaust gas analyzers by all Federal, International, and State/Provincial agencies as below. As they are the standard methods used to measure exhaust gas constituents, some discussion of their nature and effectiveness is warranted.

## NDIR Definition:

NDIR stands for **Non-Dispersive InfraRed**. This technology is used to measure the concentration of a gas (actually, the number of molecules in the optical path) by determining how much infrared energy is absorbed at a select wavelength band that corresponds to a resonant mode spectrum of the molecule being analyzed.

For example, the CO<sub>2</sub> molecule has a strong resonance at a frequency relating to the 4.26 micron electromagnetic wavelength – near infrared. So – CO<sub>2</sub> will strongly absorb infrared energy at this select wavelength. The more CO<sub>2</sub> molecules there are in the optical path – the more energy gets absorbed – although this is a highly non-linear function.

The gas analyzer determines how much energy is absorbed (the infrared absorption) at a specific molecular resonance of a particular gas, and then relates this absorption to gas concentration – the characteristic instrument curve for the gas being analyzed.

This technique is very specific to the particular resonance of each gas molecule being measured, so it works well to measure certain gases in mixes of other gases – providing that appropriate absorption bands unique to each gas can be isolated.

In general, it is the technique of choice for measuring such common gases as CO (Carbon Monoxide), CO<sub>2</sub> (Carbon Dioxide), SO<sub>2</sub> (Sulfur Dioxide), NO<sub>2</sub> (Nitrous Oxide Anesthetic Gas) and a variety of Hydrocarbons (generally the Alkane group – looking at

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the H-C stretch resonance) – but other hydrocarbons are readily measurable as well – for example fluorinated hydrocarbon anaesthetic agents.

This technology is cost effective, robust, stable, well proven, and by far the most popular method for measuring the gases above – with 100,000's of installations operating worldwide, from CEM to Anesthesia Machines, to Exhaust Gas Analyzers, and a variety of industrial applications.

## **EPA Method Compliance:**

The NDIR gas measurement technology is generally recognized as one of the technologies of choice for analyzing emission gases. The NDIR method is specified as an appropriate measurement technology by the EPA for several gases in official EPA-Defined test methods – given below:

EPA Method 3A: NDIR for measuring CO<sub>2</sub> emissions from Stationary Sources

EPA Method 6C: NDIR for measuring SO<sub>2</sub> emissions from Stationary Sources

EPA Method 10: NDIR for measuring CO emissions from Stationary Sources

EPA Method 21: NDIR for measuring VOC Leaks

EPA Method 25B: NDIR for measuring VOCs.

In addition, NDUV (same approach as NDIR, but at an Ultra-Violet wavelength) is an EPA specified measurement method in:

EPA Method 7B: NDUV for measuring NO<sub>x</sub> from Stationary Sources.

## **Mobile Emissions Source Test Compliance:**

All Domestic and International Federal and State mobile emission programs (e. g. BAR-74, BAR-80, BAR-84, BAR-90, BAR-97, ASM, IM-240, FTP, etc) specify NDIR as the gas measurement technology of choice for measuring CO, CO<sub>2</sub>, HC (measuring gasoline vapor, C<sub>4</sub> – C<sub>10</sub> as Hexane) in the exhaust streams of internal combustion engines.

In addition, NDUV is recognized as one of the measurement technologies of choice for NO<sub>x</sub> emission measurement from the same sources.

NDIR has also been the analytical technology of choice for the measurement of C<sub>1</sub> – C<sub>20</sub> (Methane and above) in a variety of applications, from wasteful site emission measurements to VOC elimination or recovery installations.

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## **NDIR Instrument Utility and Costs:**

NDIR-based analytical equipment is available in a variety of styles, from hand-held portables to bench-top commercial and laboratory-grade analyzers to complete CEM installations. This equipment is relatively low cost, robust, stable, and easy to operate – lending itself to a variety of commercial applications. It does not require frequent recalibration to remain accurate, and has demonstrated stability and longevity – with many instruments providing decades of use in the field.

## **Comparison of NDIR to other analytic technologies:**

### **NDIR Vs FTIR:**

The main difference between NDIR and FTIR (or the equivalent continuous spectral analysis technology) is that NDIR measured electromagnetic energy in a particular bandpass range – generally determined by an interference flatter in the equipment – and chosen to align with the infrared absorption spectrum of a specific gas molecule.

FTIR (or the equivalent) examines the electromagnetic absorption spectrum continuously across a range of wavelengths. Thus, it is more versatile – but less specific to a particular gas. In general, FTIR technology is used in a comparative, batch process manner – in which the equipment is first characterized using a variety of calibration gases, and then the sample gas is run and compared to the calibration gas signature and energy absorption magnitude.

From this data, the gas concentration for specific gases with unique spectral signatures may be made. Correlation between NDIR and FTIR should be high, although they should generally be verified by actual gas measurement using both approaches.

FTIR or other continuous spectrum analytical technologies are costly, complex, require significant operator expertise, and are generally considered to be ‘laboratory class’ instrumentation. They have yet to find much application in high volume commercial-grade field equipment.

### **NDIR Vs FID:**

Both NDIR and FID (Flame Ionization Detection) are analytical technologies of choice for the measurement of HC compounds. The difference between NDIR and FID is that NDIR makes use of the infrared frequency resonance absorption characteristics of HC molecules for measurement (generally, the H-C stretch resonance, although other

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resonance's may be used as the HC molecule becomes more complex), while the FID approach strips the hydrogen from the HC molecule and then ionizes the remaining Carbon atom into an emissive state. The Carbon atom emission frequency intensity is then measured, and a relationship made between the energy measured and the concentration of Carbon ions made (from the characteristic instrument curve and subsequent calibration with a known gas and concentration). Using this technique, the 'equivalent HC' concentration may be determined in the sample gas.

It is important to realize that both NDIR and FID are largely non-specific – in that FID disassembles the HC molecules in the gas stream before analysis, and NDIR generally looks at molecular resonance's which are commonly found in a variety of HC molecules.

In either case, the resulting HC gas concentration of the HC gases in the measurement stream determined by either technique is reported as 'equivalent concentration of a specific HC gas' – usually (but not always) the gas used to calibrate the instrument.

FID may be used to measure any HC compound – as the technique isolates the Carbon atom from the molecule and then measures its emissive energy. The resulting response is strictly a function of the concentration of Carbon atoms in the measured gas.

NDIR is more molecule –specific, in that each HC molecular structure has its own IR absorption signature and magnitude – so some molecules produce more IR absorption in a particular wavelength band than others.

However, both the NDIR absorption and Carbon atom emissive relationships are generally tied to the number of Carbon atoms in the molecule – so NDIR and FID analytical technologies have similar responses for many HC molecules.

Correlation between NDIR and FID are very gas-composition specific, and should generally be verified by actual gas measurement of representative sample gas using both approaches.

### **NDIR Vs ElectroChemical Sensors:**

NDIR, being non-destructive in nature, is applicable to the measurement of partially or fully reacted gas molecules. Some gases are either too small or tightly bound to exhibit significant resonant absorption spectra at practical measurement wavelengths, and do not lend themselves to NDIR or even NDUV analytic techniques. However, many of these gases are chemically reactive, and so do lend themselves to measurement with gas-specific electro-chemical sensors.

These sensors generally produce an electrical analog of the gas concentration, and are both zero-stable and linear. They tend to vary in gas sensitivity with time and temperature, however, and require thermal compensation and relatively frequent span calibration to correct for temperature

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or time – related span drift. However, this is one of the technologies of choice for Oxygen, NO, CO (Concentrations below 1.0%), SO<sub>2</sub>, Ammonia, Chlorine, and other reactive gases. They are commonly used for ambient atmosphere toxic gas detection products – where low level detection and zero stability are of paramount importance and toxic gases may exist in such low concentrations as to make NDIR methods impractical.

This technology is not usable for fully reacted gases (CO<sub>2</sub> or HC), Inert Gases (N<sub>2</sub>, He, etc), or for high concentrations. The chemical sensors used are based on measuring a chemical reaction in a gas stream where the reactions are limited by the amount of gas diffusing into the electrolyte. They become highly non-linear and unstable with high gas concentrations, and are more suitable for highly diluted gas streams – flue gas or ambient air applications. They are generally unsuitable for concentrated gas streams – such as internal combustion exhaust.

In general, the most common use of the ElectroChemical sensor method is for oxygen analysis – where it is by far the dominant method, with millions of commercial implementations. The sensors are generally low cost gas analysis solutions, with analyzers selling for a few hundred dollars (toxic gas detectors) to several thousand dollars for bench top or commercial industrial implementations.

## **NDIR Vs Gas Chromatography (GC):**

Gas Chromatography (GC) is a method by which a gas mixture is first separated into specific species, and then quantified using a general method. Many GC systems use thermal conductivity methods to determine the mass flow of the effluent from a separation column – in which smaller molecules move faster and therefore are expelled earlier.

The advantage of such a system is that it is gas-specific and provides a unique output for each molecule in the test gas mixture.

However, it is a batch-process analytical technique rather than a time-continuous method, requires significant operator expertise to use, and is generally considered time-unstable – requiring the equipment to first be calibrated on a known gas standard and then measurements made.

## **NDIR Vs Mass Spectroscopy (MS):**

Mass Spectroscopy (MS) is a method by which the test gas is first ionized and then propelled through a magnetic or electrical field. The trajectory of the gas molecules is thus a function of the molecule mass and the ionization charge reaction to the applied field.

However, rather like GC above, it is generally a batch-process analytical technique rather than a time-continuous method, requires significant operator expertise to use, and is generally considered time-unstable – requiring the equipment to first be calibrated on a known gas standard and then measurements made.

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