

Exposure Assessments with Direct Reading Instruments On Construction Sites

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Introduction

Every occupational safety and health (OSH) professional must be aware of two important characteristics of the construction industry:

- The temporary nature of the activities;
- The variability of the process.

Construction operations are mostly temporary, and this means that the time factor is always important (Espino, 2011). Also, their activities are highly variable, and this presents important challenges for the OSH professionals in charge of supervising the work.

Many times, decisions must be based on industrial hygiene measurements. However, there is often no time to send samples to a laboratory, and wait for the results. This is due to the characteristics explained above. These decisions may be required to select the appropriate personal protection equipment, designing the ventilation system, the type of training that the workers should receive, etc. In these cases, direct reading instruments may be used to evaluate environmental conditions.

This paper shall focus on the use techniques of direct reading instruments to measure parameters in construction work. The information presented is valuable for those OSH professionals who must make fast decisions in the workplace on atmospheric conditions in construction work. Some examples of applications of the technical proposals will also be shown.

Direct Reading Instruments

In this case, we shall define direct reading instruments as those that measure environmental contaminants directly in a screen or an analogical dial. It is not necessary to collect the contaminant and send it to a laboratory to be quantified. There are many different kinds of direct reading instruments in the market. They can detect from one to six different gases simultaneously, depending on the model.

Direct reading instruments have two types of sensors: specific, and non-specific. The former are designed to detect a specific gas, for example, oxygen (O₂), carbon monoxide (CO), hydrogen sulfide (H₂S), etc. The latter provide us with a reading of a group of substances, for example, volatile organic compounds, and flammable gases. We must know and understand the limitations of each sensor, in order to make correct decisions in the field.

Specific sensors are the easiest to interpret. Under appropriate conditions, they provide quite precise readings of the concentration of the agent for which they were designed. However, care must be taken so that other contaminants do not affect the sensor's sensibility. There are sensors that will give incorrect readings when they are exposed to other contaminants. The manufacturer's manual should be consulted to avoid these interferences, and to be able to take the appropriate corrective measures.

Non-specific sensors provide readings of a wide range of compounds. One must take into account the reference gas used, generally the same as the calibration gas. The instrument will read as if the reference or calibration gas is present, and the corresponding adjustments must be made, to obtain valid measurements. For example, it is common to calibrate a flammability sensor, which reads the lower explosive limit (LEL), with methane (CH₄). However, methane will not necessarily be found in the environment that is being measured. Depending of which gas is present, the reading can be below or above the real concentration. In the case of photoionization detectors (PID), these will provide a reading of the concentration of the total volatile organic compounds. That is, they will provide a non-specific reading of the compound that is present. These instruments are generally calibrated with isobutylene (C₄H₈), and adjustments must also be made, in order to obtain reliable data.

Flammable Gases Sensors

Sensors for flammable gases are used to evaluate the level of flammability of an atmosphere, on the basis of the lower explosive limit (LEL). Depending on the legislation that applies, the maximum limits to enter the atmosphere may vary between 10 and 20 per cent of the LEL. The instructions provide us with the LEL of the different substances; other important references are the product safety data specifications. For example, for a substance with a LEL of 5000 ppm (parts per million), 10% of the LEL would be at a concentration of 500 ppm; a concentration of 20% of the LEL would be at a concentration of 1000 ppm. These instruments can be programmed to give readings in ppm or in percentages of the lower explosive limit.

There are two common types of flammability sensors in the direct reading instruments: catalytic sensors and non-dispersive infrared sensors (NDIR). The catalytic sensors are the most common and more inexpensive. They generally come incorporated into the "off-the-shelf" instruments. They are sensible to lighter gases, but they need oxygen to operate (>10%), and may provide ambiguous readings in concentrations above the LEL, and can read gases with a content of up to 9 carbons (nonane) (Henderson, 2012). The heavier gases cannot pass through the sensor's filter. NDIR sensors can read up to 100% v/v, and can read heavier gases; additionally, they do not need oxygen to operate, so they can be used in inert atmospheres. The problem is that they do not read hydrogen gas, and are much more expensive than catalytic sensors. A common application of this type of sensors (NDIR) is to evaluate atmospheres during cleaning or maintenance of fuel tanks.

We have repeatedly observed an incorrect use of instruments with catalytic sensors to evaluate the atmospheres of fuel tanks. For example, diesel contains between 9 and >23 carbons, so an NDIR sensor must be used. A catalytic sensor would give us incorrect readings, jeopardizing the lives of workers entering the area.

Toxic Gases Sensors

These sensors are the easiest to use, and provide us with direct readings of the contaminants for which they were designed. As mentioned above, it is important to analyze if any of the gases present in the atmosphere can affect the sensor's sensibility of the gas we wish to measure.

Photoionization Detectors (PID)

The third type of sensor we shall analyze is the photoionization detector (PID), which measures volatile organic compounds (VOC's). This is an extremely useful sensor to evaluate the levels of toxicity of volatile substances. Flammable gases sensors generally read in LEL percentage, so readings would be in hundreds to thousands ppm (10,000 ppm = 1% v/v). Most permissible maximum limits are in dozens to hundreds ppm (ACGIH, 2012).

It is common in construction work to use paints and other volatile coatings, and monitoring of air concentrations is required. In these cases, we can use the PID's to evaluate concentrations of health limits, and the flammable gases sensors to measure explosive levels. Both measurements are indispensable to guarantee the health and safety of the workers.

Calibrating Direct Reading Instruments

All direct reading instruments should be calibrated periodically, according to the manufacturer's instructions. Most manufacturers base their instructions in the recommendations of the International Safety Equipment Association (ISEA). This procedure establishes that a bump test or a complete calibration to test the sensor's operation should be done *before* each day of use, using a gas with a known concentration. If the instrument does not pass the operation test, a complete calibration should be done. The ISEA guide also describes a procedure to extend the calibration period. (ISEA, 2002).

In our experience, we have found that many OSH professionals confuse complete calibration with the bump test, and dangerously extend instrument revision periods. Another aspect to be considered is that in several Latin American countries it is difficult to import calibration gases, in addition to the delivery prices. Calibrating gases are considered hazardous materials, and are subject to applicable restrictions for international shipment of these products.

It should be considered that all the direct reading instrument sensors should be calibrated. In other words, if you have an instrument of six gases, there should be six different calibration gases or one (or several) mixture(s) which contain these gases. This can be expensive, and should be considered when selecting equipment. Equipment that is not calibrated should not be used to measure, since it can provide incorrect readings.

Use of Direct Reading Instruments in Construction Work: Practical Applications

OSH professionals in charge of construction work need information on concentration of flammable and toxic gases, to be able to recommend the appropriate controls. The first step is to select what is to be measured. Gases or vapors that are sufficiently volatile to form a toxic or flammable atmosphere should be considered. Based on the experience of this author, substances with a boiling point lower than 150°C should be considered, as well as substances with maximum permissible limits that are lower than 100 ppm. It is important to use technical criteria to select these substances.

Once the substance to be evaluated is selected, the second step consists in selecting the equipment and the types of sensors to be used. Selection of the type of equipment and sensor should be based on the number of carbons, volatility, toxicity, relative density, and the calibration gas used to calibrate the equipment.

Flammability Measurements

Let us take the case of measuring the flammability of a gas. If we wish to measure the percentage of the lower explosive limit in an atmosphere that contains toluene ($C_6H_5CH_3$), we would have to answer several questions:

- What type of sensor shall we use? In this example we will use a catalytic sensor.
- What calibration gas shall we use to calibrate the sensor? In this example we shall use methane.
- Can we measure toluene with this type of sensor? The answer is yes, because toluene has less than 9 carbons.
- What would be the correction factor for toluene if we calibrate with methane? The relative response of the sensor calibrated with methane would have to be calculated for toluene.

The manufacturer should provide the relative response of the sensor, and it will depend on the sensor used by the equipment. For example, the relative response of a catalytic sensor for toluene – commonly used in several equipment – is 40% (Henderson, 2012). This means that the equipment will read 40% of the real value. To correct the value, the reading must be multiplied by the reciprocal of the relative response.

$$FC = 1/RR$$

Where FC is the correction factor and RR is the relative response. For this example, the correction factor would be equal to 2,5. The value indicated by the instrument must be multiplied by 2,5 to obtain the real value of the lower explosive limit for an atmosphere containing toluene, if the sensor was calibrated with methane. For example, if the instrument reads 5% of the LEL, the correct reading would be 12,5%. Toluene concentration would be at 12,5% of the LEL, and not at 5% as read by the instrument! This difference is important, because it would place us above the limit normally accepted, of 10% of the LEL.

Toxicity Measurements

Measurements of toxic gas concentration can be done with specific sensors, or calculated on the basis of measurements with non-specific sensors. The usual in construction projects is having to measure atmospheres where there is no specific sensor; for example, when applying special coatings and paints. Generally, these paints and coatings contain solvents and other volatile organic compounds such as xylene, toluene, ethyl benzene, isobutyl, nonylphenol, etc.

The compounds mentioned above have limits in the order of dozens of ppm (10-100 ppm) (ACGIH, 2012). To measure these concentrations, an instrument with better resolution than one measuring in percentages of LEL is needed. We could use a portable photoionization detector (PID) for this measurement. These instruments can measure in ppm (parts per million), and even ppb (parts per billion)! However, we must also consider the gas used to calibrate the instrument, generally isobutyl.

The units read by the PID would be in ppm or mg/N-m³ (milligram per cubic meter of air at normal temperature and pressure), as isobutyl units, expressed as ppm_{ISO} or mg/m³_{ISO}. To calculate the real concentration, you would have to multiply the reading in isobutyl units by the correction factor of the instrument for the gas we wish to measure. Correction factors are provided by the manufacturer of the equipment, and can vary with each trademark. Another important aspect to consider is the photoionization energy of the volatile compound. The light bulb used in the PID must provide enough ultraviolet energy to ionize the compound, or the instrument would read zero. The manufacturer's equipment tables must be consulted, to know the ionization energy of each compound.

Let us take, for example, the case above, where we have an atmosphere containing toluene. As the TLV (threshold limit value) (ACGIH, 2012) is 20 ppm, it is difficult to measure these levels with sensors that read in LEL percentages. Toluene's LEL is 1,2% in volume (Wikipedia, 2013); in ppm's, the LEL would be 12.000 ppm; 10% would be equal to 1.200 ppm; and 1% of the LEL would be equal to 120 ppm. The TLV of 20 ppm would be equal to 0,17% of the LEL, and our instrument would probably not have the required resolution to measure this level; however, the PID would.

Let us assume that the correction factor for toluene is 0,5 for a PID calibrated with isobutyl, using a light bulb of 10,6 eV. If the PID reads 20 ppm, the real concentration would be equal to: 20 ppm * 0,5 = 10 ppm. This is true only if and when the toluene is the only gas present in the atmosphere. If other gases were present, the reading would not be correct, and additional calculation would be required. An OSH professional could then determine that when the PID reads >40 ppm_{ISO}, respirators for volatile organic compounds should be used. The reading is direct and instantaneous, with no need to send samples to a laboratory. Also, the flammability limit is much higher, and the LEL sensor is probably reading "0" at this time.

Things would get more complicated if there was a mixture of volatile organic compounds in the atmosphere. In this case, the correction factor of the mixture would have to be calculated using the following formula:

$$C_{Mix} = \frac{1}{\sum \frac{X_i}{CF_i}}$$

Where C_{mix} is the correction factor of the mixture; X_i is each compound in the mixture; and CF_i is the correction factor of each compound.

We must also know the maximum permissible limit of the mixture, to be able to compare the readings. In the case of aliphatic, cycloaliphatic, and aromatic compounds, we can use the reciprocal formula recommended by the ACGIH (ACGIH, 2012):

$$LMP_{mix} = \frac{1}{\sum \frac{X_i}{LMP_i}}$$

Where LMP_{mix} is the maximum limit of the mixture; X_i is each compound in the mixture; and LMP_i is the maximum permissible limit for each compound. As an example, we shall use a paint that contains 15% styrene (C_8H_8) and 85% xylene ($C_6H_4(CH_3)_2$) (information obtained from the MSDS). The PID reads 120 ppmISO; the correction factors, according to the manufacturer of the PID are 0,4 for styrene, and 0,6 for xylene; the LMP is 50 ppm for styrene, and 100 ppm for xylene.

$$CF_{mix} = \frac{1}{\left(\frac{0,15}{0,4} + \frac{0,85}{0,6}\right)} = 0.56$$

$$LMP_{mix} = \frac{1}{\left(\frac{0,15}{50} + \frac{0,85}{100}\right)} = 87 \text{ ppm}$$

Where: 0,15 is 15% styrene; 0,4 is the styrene's CF; 0,85 is 85% xylene; 0,6 is the xylene's CF; 50 ppm is the styrene's LMP; and 100 ppm is the xylene's LMP. In conclusion:

- If the PID reads 120_{isobutyl}
- Multiply by the CF of 0.56
- The real concentration of the mixture is = 67.2_{mix} ppm
- 67.2 ppm < LMP = 87 ppm, and the LMP is not exceeded.

PID Alarms

To program the PID alarm, the mixture's LMP is divided by the mixture's correction factor, to calculate the limit in isobutyl units. To continue with our example:

- $LMP_{mix} = 87 \text{ ppm}$
- $CF_{mix} = 0.56$
- Alarm limit = $87 \text{ ppm} / 0.56 = 155 \text{ ppm}$

For mixtures of gases and vapors, the most toxic compound is taken, which controls the alarm for the mixture. The PID is programmed for the compound with the lowest isobutyl units,

and this will give us the mixture's alarm. For example, for a mixture of ethanol, turpentine, and acetone, we would have the following information:

Substance	CF _{iso} (10.6eV)	LMP	Alarm ppm _{ISO}
• Ethanol	• 10.0	• 1000	• 100.0
• Turpentine	• 0.45	• 20	• 44.5
• Acetone	• 1.2	• 500	• 416.7

Table 1: Calculating Alarm Levels

According to the information provided, the substance for which the PID alarm shall be programmed would be turpentine, with 44,5 ppm.

Summary

Due to the transitory nature and variability of the construction industry activities, it is important that the OSH professionals be able to take measurements in the field, with direct reading instruments. These measurements will enable them to make important decisions in selecting the required control measures.

Direct reading equipment is usually used to measure toxic gases and vapors, or flammable atmospheres. Toxic gases can be measured with specific or non-specific sensors; flammability levels are usually measured with catalytic sensors or infrared non-dispersive sensors, depending on the application.

Sensors used to measure flammable atmospheres should be able to measure concentrations in percentages of the lower explosive limit; these concentrations are usually in the order of hundreds to thousands of ppm. These sensors may not have the required resolution to measure the levels of toxicity that is required in accordance with the maximum permissible limits. Another important aspect to consider when using instruments with flammability sensors is the adjustment of the reading to the calibration gas.

Portable photoionization detectors are the best option to evaluate the maximum permissible limits for occupational health effects. These instruments are easy to use, and can measure concentrations of volatile organic compounds. The use of volatile paints and coatings is common in the construction industry, and can be measured with a photoionization detector. As is the case with flammability sensors, it is necessary to adjust the instrument's reading to the calibration gas.

Bibliography

ACGIH. (2012). *TLV's / BEI's 2012*. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists.

Citytech. (2011). *City Technologies 4P-75 Product Data Sheet*. Hampshire, United Kingdom.

Espino, J. C. (2011). *Curso de Seguridad en la Construcción*. Panamá, Panamá: Cámara Panameña de la Construcción.

Henderson, B. (2012). *Methods and Applications for Exposure Assessment Chemical Detection in Real-Time*. *AIHCE 2012*. Indianápolis, Indiana.

ISEA. (2002). *ISEA Statement on Verification of Calibration for Direct Reading Portable Gas Monitors in Confined Spaces*. Arlington, VA.

Wikipedia. (2013). *Flammability limit*. Consultado el 6 de marzo de 2013:
http://en.wikipedia.org/wiki/Flammability_limit.