Blowing Up Will Ruin Your Whole Day

After oxygen, the detection of combustible gases and vapors is the next most important atmospheric parameter to measure. According to the OSHA (US Occupational Safety and Health Administration) rule contained in 29CFR1910.146 or "the Confined Space Standard:"

> "Before an employee enters the space, the internal atmosphere shall be tested, with a calibrated direct-reading instrument, for oxygen content, for flammable gases and vapors, and for potential toxic air contaminants, in that order."

So OSHA feels that measuring combustible gases and vapors is the second most important atmospheric parameter to measure.

Humans can't measure flammability

While in some cases humans can smell and even taste some flammable gases and vapors, we are not calibrated to know when we have reached a concentration that is potential flammable. When we smell gasoline we can't tell if there is a flammable concentration or not. Because we can't measure flammability we need to use and understand detection technologies that will provide us with the information we need to make decisions. In this white paper we will discuss:

1. How the most common combustible gas sensors work
2. The limitations of "catalytic bead" sensors
3. Why there may be a difference between calibration gas and measurement gas
4. Options that can be used for measuring combustible gases and vapors
5. How multiple combustible gas detection technologies may be useful in reaching a decision in flammable atmospheres

Flammability Range

The flammable range of a chemical is the concentration of that gas that lies between its Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL). Below the LEL the gas or vapor is too "lean" to burn or it is full starved. Above the UEL the gas or vapor is too "rich" to burn or it is oxygen deprived. Concentrations within the flammable range will burn or explode if a source of ignition is present.

Here are the LELs and UELs of some common gases and vapors according to NFPA 325 "Guide to Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids, 1994 edition:

Gas/Vapor	**LEL* (% vol)**	**UEL* (% vol)**
Acetone	2.2	12.8
Benzene	1.2	7.8
Carbon Monoxide	12.5	74
Diesel	0.8	10
Ethylene Oxide	3.0	100
Gasoline	1.4	7.6
Hydrogen	4.0	75
Methane	5.0	15
MEK	1.8	11.4
n-Pentane	1.5	7.8
Propane	2.0	9.5
Toluene	1.2	7.1

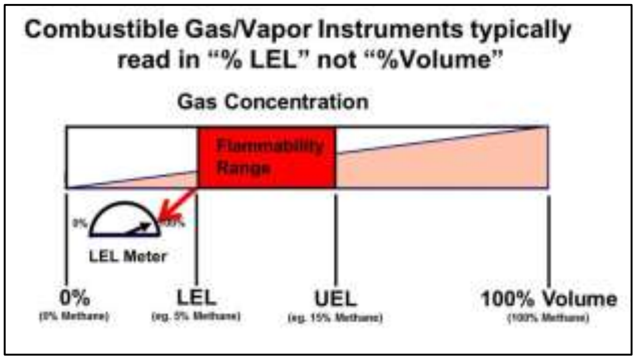
- Note that LELs and UELs can vary between reference sources
- CO and EtO have very wide flammability ranges because they carry their own oxygen
- Meter accuracy can drastically affect your LEL readings
- Therefore, always be VERY CONSERVATIVE when making LEL decisions

Combustible Gas Detectors Typically Read in % of LEL not % Volume

As the following diagram shows, most combustible gas detectors read in a 0-100% of LEL scale. In theory, when these meters read 100% there is enough flammable gas/vapor in the air to allow combustion to take place and below 100% of LEL there should not be enough flammable gases/vapors in the air to support combustion. Most combustible gas detector DO NOT measure above 100% of LEL up to 100% by volume. While some specialized detectors do so, this is not as common. To

14502 Stetson Road, Los Gatos, CA 95033
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

illustrate this difference, 5% by volume of methane in air is the same as 100% of LEL. Put another way, 5% by volume of methane in air will ignite while 4% will not and if a confined space meter is calibrated to a methane scale 5% by volume of methane will read 100% on the meter.



Wheatstone Bridge Catalytic Bead LEL Sensors

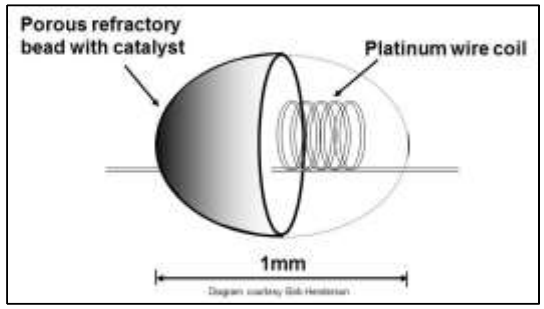
The most common type of LEL sensor used in handheld gas detectors for the measurement of combustible gases and vapors is the Wheatstone Bridge Catalytic Bead sensor. The catalytic "Hot Bead" combustible sensor detects combustible gases and vapors by catalytic oxidation. When exposed to gas, an oxidation reaction causes the sensing or "active" bead to heat. This bead contains a wire. As a hot wire carrying electricity has greater resistance than a cold wire the Wheatstone bridge subtracts the resistance of a cold reference wire from that of the hot detector wire and the net increase of resistance correlates with the amount of flammable gas/vapor. The greater the resistance on the hot wire correlates with more flammable gas/vapor. Because this is an oxidative process it requires oxygen to detect flammable gases and vapors. Most manufacturers require a minimum of 12-16% oxygen for their sensor to work although at least one manufacturer reports their LEL sensors operate down to as low as 2% oxygen. This type of sensor was developed by Dr. Oliver Johnson of Standard Oil Co. of California (now Chevron) in 1926-1927. Virtually EVERY combustible gas monitor today is derived from this design and is variously called the "Wheatstone Bridge," "Catalytic Bead" or simply "cat bead" sensor.

What is a Catalyst?

According to Miriam Webster a catalyst is:

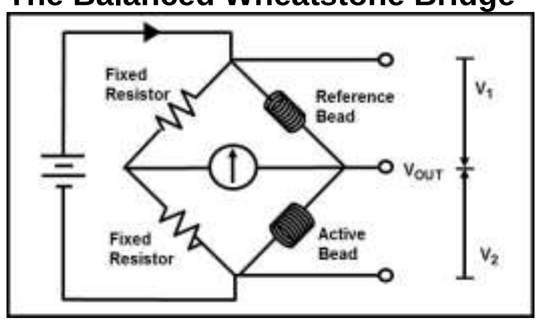
> "a substance that enables a chemical reaction to proceed at a usually faster rate or under different conditions (as at a lower temperature) than otherwise possible"

Platinum or palladium are two of the catalysts commonly used in the catalytic bead to facilitate the oxidation (burning) of flammable gases and vapors at lower (safer) temperatures (~250ºF, ~120ºC).



A coiled wire is used to maximize the surface area of catalyst. It is put into a porous ceramic bead to keep it from flexing like a "Slinky" and shorting out on itself. This adds to the durability of the sensor and helps it to resists shock.

The Balanced Wheatstone Bridge



As a gas/vapor burns on the active bead it heats up and has greater resistance than the reference bead. The "Wheatstone Bridge" circuit measures the difference in resistance from the active bead to the reference bead. The reference side is there to establish the baseline resistance. Changes in resistance due to atmospheric changes (like temperature) that are not related to flammability are compensated for by the reference bead. The reference bead output is subtracted from the active bead output using the Wheatstone Bridge electrical circuit so that the resulting change in resistance

14502 Stetson Road, Los Gatos, CA 95033
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

only reflects the effects of the flammable gas/vapor without atmospheric effects.

- **Active bead – Reference bead = Net increase in resistance = Flammability**

The Wheatstone bridge catalytic bead sensor is like an electric stove

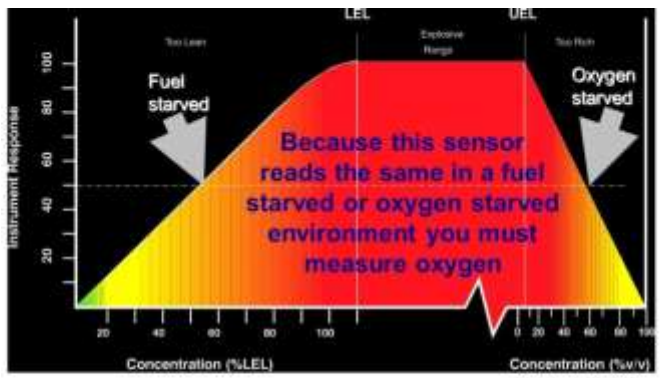
While this discussion of the inner workings of the catalytic bead sensor may seem complicated this sensor is fundamentally quite simple. Imagine an electric stove where one element has a catalyst and one doesn't. Both elements are turned on low. Low normally wouldn't support combustion or "oxidation." But one stove element has a catalyst on it while the other doesn't. The element with the catalyst on it "burns" or oxidizes the flammable gas/vapor at a lower temperature level and heats up relative to the burner without the catalyst. The hotter element has more resistance and the Wheatstone Bridge measures the difference in resistance between the two elements.

A Primary Measurement

The Catalytic Bead LEL sensor is a primary measurement because if something burns it will burn on this sensor. This is one reason for the dominance of the catalytic bead sensor in handheld detectors. We will discuss other means of measuring flammability, but they are ALL measuring some secondary attribute of flammable gases and vapors and all of them have significant "blind-spots" relative to the catalytic bead sensor.

Catalytic Sensors Require Oxygen

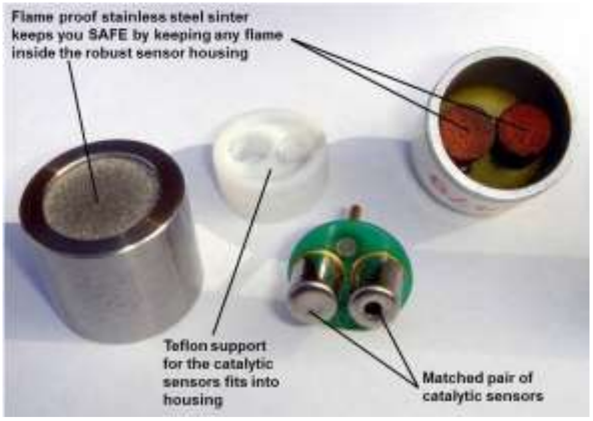
Because it is a catalyzed oxidative process, oxygen is required. The OSHA confined space standard recognizes this because it says to measure oxygen FIRST. This is because the Wheatstone bridge catalytic bead combustible gas sensor can read the same in a fuel starved (below LEL) situation as it does in an oxygen starved (above UEL) situation. Measuring oxygen first guarantees that one is in the below LEL situation. The following chart illustrates this effect. One can see a line at about 50% of LEL extending across the chart. It shows that the 50% of LEL reading in the "too lean" environment is the same as the 50% of LEL in the "too rich"



environment.

Making the Electric Stove Safe for Use in Flammable Atmospheres

The Wheatstone bridge catalytic bead sensor is essentially a little electric stove. Unfortunately, electric stoves could possibly ignite a potentially flammable atmosphere. To prevent this from happening, the sensing elements of these sensors are contained in a robust explosion proof housing and gas/vapors enter the sensor through an explosion resistant sinter. This sinter allows gases and vapors to come in, and it prevents any flame from coming back out. The following photograph shows the two burner electric stove removed from the robust sensor housing with a single shared sinter on the left. The white plastic in the background helps to stabilize the sensor elements from moving around should it get dropped. On the right one can see how another manufacturer achieves the same goal by putting the sinters on each of the sensing elements.



Understanding the Variances in Catalytic Bead Sensor Responses

The operation of the catalytic bead sensor guarantees that it will respond differently to different gases. That can result in issues like the two below that we will later explain:

- A fire department finds that their LEL sensors calibrate correctly but don't "see" natural gas
- A fire department arrives at a confined space rescue and finds that their meter doesn't agree with the contractor's meter

Two mechanisms affect the performance of Wheatstone bridge LEL sensors and reduce their effectiveness when applied to all but methane

1. Gases burn with different heat outputs at their LEL
2. "Heavier" (low vapor pressure) hydrocarbon vapors have difficulty diffusing into the LEL sensor and reduce its output

Gases & Vapors burn with different heat outputs

At their LEL, gases and vapors produce different heat outputs. Some, like methane, produce a lot of heat. Some, like diesel, produce much less heat at their LEL. For example, most "gas" stoves are setup for Natural Gas when they ship. When used on "LP" or "Propane" gas these stoves need to be recalibrated with new jets and new regulator pressure because LP/Propane burns with approximately half the heat of Natural Gas. For the stove to be effective when used on LP/Propane it has to be recalibrated. This is an example of why LEL sensors will respond differently to different gases.

Heavier Hydrocarbons have difficulty getting into the sensor

While gases go right through the explosion proof sinter on top of the catalytic bead sensor, heavier hydrocarbons with lower vapor pressures and higher boiling points have increasing difficulty getting passed the sinter as they get heavier. To illustrate this, imagine a pitcher:

- Fill it with methane and pour it out on the floor, how much hits the floor?
    - Methane has a vapor pressure of +760mm/Hg so it won't even stay in the pitcher and none hits the floor, it quickly diffuses into the air
- Fill it with ethyl ether and pour it out
    - Most evaporates on the way to the floor because ether has a vapor pressure of 440 mm/Hg, some may hit the floor but it will evaporate in minutes

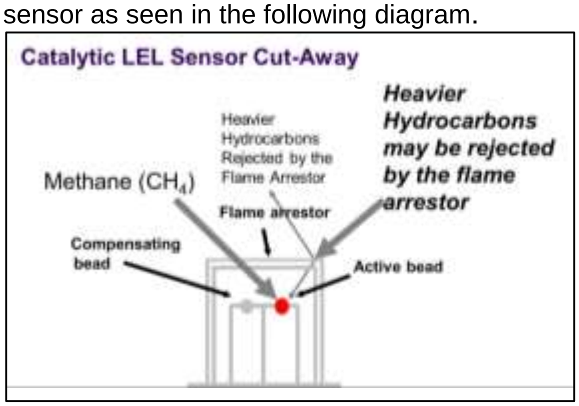
- Fill it with diesel and pour it out
    - It all hits the floor, it's all there an hour later, a week later and even a year later because it has a vapor pressure of 0.4 mm/Hg

Summary of VPs and BPs for some common hydrocarbons

A more technical way of looking at this is the following chart. We can see that as the size of the flammable gas/vapor molecule increases the number of carbons increases, the vapor pressure drops and the boiling point increases.

Name	Formula	Vapor Pressure (@20°C) mm Hg	Boiling Point (°C)	Boiling Point (°F)
Water	H2O	17.54	100	212
Ethane	C2H6	>760	-67	-89
Acetone	(CH3)2CO	200	13	56
Isopropanol	C3H8O	40	27	81
Propane	C3H8	>760	-43	-45
Methane	CH4	>760	-107	-161
Butane	C4H10	>760	-18	-0.5
Pentane	C5H12	465	2	36
Gasoline	C5-10	38-300	10-93	50-200
Hexane	C6H14	260	20	68
Heptane	C7H16	46	37	98
Octane	C8H18	5	52	126
Decane	C10H22	2	79	174
Diesel	C11–25	0.4	160-371	320-700
Dodecane	C12H26	0.3	102	216
Hexadecane	C16H34	~0.01	114	237
Docosane	C22H46	<0.001	164	327
Triacontane	C30H64	<0.0001	232	450

As the vapor pressure decreases and the boiling point increases the "heavier and stickier" vapor has less chance of getting into the sensor as seen in the following diagram.



LEL Sensor Response can vary with the Gas/Vapor

The combination of different heats of combustion and varying vapor pressures means that different gases and vapors will have differing responses on catalytic bead sensors. This sensor doesn't know one gas/vapor from another. It only knows ONE thing, how much heat is produced when a gas/vapor "burns" in the LEL sensor due to catalytic oxidation. Some gases, like methane, produce a lot of heat on this sensor. Some vapors, like diesel, produce a lot less heat on this sensor. So the catalytic bead sensor doesn't know that the "lot less" heat is 10% of LEL diesel OR 3.3% of LEL methane unless the user knows what the meter is detecting because the same amount of heat is produced on the sensor by these two gases/vapors at the two different concentrations. One way to look at this is that some gases are "louder" than others on the catalytic bead sensor. This is illustrated below where the size of the font is used to illustrate the difference in response each gas/vapor has on the catalytic bead sensor at 100% of LEL. Methane is in a big font because it produces a big signal. Diesel is in a small font because it produces a small signal.

Gases/vapors may be louder or quieter than the calibration gas. Loud means that they get more response on the LEL sensor and they will go into alarm early (safe state). Quiet means that they get less response on the LEL sensor and they will go into alarm late (unsafe state).

Catalytic LEL Sensor Response

In the following charts we will take a more scientific view of catalytic LEL response. The "LEL" column represents the minimum percent volume of a gas or vapor required to ignite. The next column represents the relative sensitivity to the gas/vapor relative to methane. Put another way, the sensitivities represented are the response when 100% of LEL of a chemical is presented to a meter that was calibrated to a methane scale. The right most column shows the ignition temperature for each of the gases and vapors. The "LEL" and "Ignition Temperature" data come from NFPA 325 "Guide to Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids," 1994 edition. The "Sensitivity" data is for example only; please consult your detector manufacturer for sensitivities specific to your product.

By looking at the "Sensitivity" column in the next chart, gasoline produces less than half of the heat of methane on a Wheatstone bridge sensor. When a LEL monitor is calibrated to and reading in methane units but it is exposed to 1.4% volume or 100% of LEL gasoline vapors, the monitor will only display 48% (less than half) of the true % of LEL. If this same LEL sensor displays 48% of LEL in a mixture of gasoline and air, the actual LEL is approximately 100% because gasoline produces just 48% of the sensor output versus methane. This is dangerous because one might think that 48% of LEL (while above the 10% allowed for confined space entry) is safe enough, but in this case it really represents a flammable environment.

Gas/Vapor	LEL (% vol)	Sensitivity (%)*	Ignition Temp. F°(C°)**
Methane	5	100	999 (537)
Hydrogen	4	92	932 (500)
Propane	2	63	842 (450)
Gasoline	1.4	48	536 (280)
Acetone	2.2	45	869 (465)
Benzene	1.2	45	928 (498)
n-Pentane	1.5	45	500 (260)
MEK	1.8	38	759 (404)
Toluene	1.1	38	896 (480)
Diesel	0.8	30	NA

A more conservative means of setting the scale on a LEL monitor is to choose a calibration gas/scale whose response is closer (or even lower) than the gases that are commonly being encountered. The next chart shows that the LEL response of n-pentane (45% response) is much closer to common VOCs (Volatile Organic Compounds) like acetone (45%), gasoline (48%) and toluene (38%) than to methane. It would seem that n-pentane would be a safer calibration/scaling alternative than methane. A number of LEL monitor manufacturers calibrate their LEL sensors to an n-pentane scale so that the LEL sensor response is corrected to a more appropriate scale for most common gases and vapors.

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Diesel	0.8	30	NA

The problem with calibrating directly to n-pentane is that it ignites at 50% of the temperature of methane. In the next chart one can see that the ignition temperature of n-pentane is just 500⁰F (260⁰C) compared

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with the ignition temperature of methane which is 999⁰F (537⁰C). As the catalyst in the LEL sensor wears out over time, it loses its ability to impart energy into a gas to cause it to oxidize. A LEL sensor will lose the ability to oxidize methane long before it loses the ability to oxidize n-pentane because methane's ignition temperature is significantly higher. It is quite possible that a weakened LEL sensor that has been properly calibrated to n-pentane gas may not respond in an environment containing methane. This is of critical importance because methane is one of the most common flammable gases encountered due to its prevalence not only in sewers but also because it is the dominant component of natural gas. For this reason, a number of manufacturers insist on a methane calibration for their LEL sensors because it is the best and most rigorous test of the LEL sensor to make sure that it remains viable in the widest variety of environments.

Setting the scale is not dependent on the of calibration gas

One does not have to calibrate on n-pentane to set the LEL sensor to an n-pentane scale. Correction Factors (CFs, also known as "Response Factors") can be used during calibration or electronically applied by the gas monitor to correct the reading to the intended target gas while still calibrating on methane. This is known as a "simulant" or "surrogate" calibration.

14502 Stetson Road, Los Gatos, CA 95033
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

What is a Correction Factor?

A Correction Factor (CF) is a measure of the sensitivity of the LEL sensor to a particular gas or vapor. Manufacturers challenge their sensors with a known concentration of a flammable gas and measure the sensors response to create correction factors. A low CF means that the LEL sensor is very sensitive to a gas or vapor. A high CF means that the LEL sensor does not have as good sensitivity to a gas or vapors. Corrections factors are scaling factors, they do not make a LEL sensor specific to a chemical, they only correct the scale to that chemical. Here are some examples of the application of correction factors:

- LEL reads 10% of LEL in methane units in a Diesel atmosphere

  $3.0_{CF^*} \times 10\%LEL_{methane} = 30\%LEL_{diesel}$

  - Then the actual concentration is 30% LEL Diesel units
- LEL reads 10% of LEL in methane units in an Ammonia atmosphere

  $0.8_{CF^*} \times 10\%LEL_{methane} = 8\%LEL_{ammonia}$

  - Then the actual concentration is 8% LEL Ammonia units

Correction factors are scaling factors. Imagine that your LEL meter is a car radio. You need to turn the volume up 3 times to accurately “hear” or measure in diesel fuel LEL units if you were first measuring in methane units. You need to turn the volume down by 20% (multiply by 0.8) to accurately “hear” or measure in ammonia unit LEL units if you were first measuring in methane units.

Applying Correction Factors (CFs)

- Applying CFs during calibration
  - One manufacturer’s LEL gas concentration reads “58% Pentane” but a closer read of the calibration gas cylinder shows that there isn’t pentane in the cylinder but “methane equivalent.” This means that the concentration of methane in the cylinder (in this case 38% by volume balance air) produces the same LEL sensor response as 58% by volume pentane balanced with air
  - Use a known concentration of gas (such as 50% of LEL or 2.5% by volume methane), multiply the LEL of the concentration of the gas by the correction factor (provided by your gas monitor manufacturer) of the gas you’d like to measure in. For example: $50\%\ LEL_{Methane} \times 1.6_{CF\ Propane} = 80$. If the meter allows you to change calibration values change the calibration value in the meter to read 80 and calibrate normally. When finished calibration show the meter the 50% of LEL methane gas and it should display 80%. This is another way to “cheat” the meter to measure in propane units
- Applying CFs manually
  - Calibrate to a known concentration of gas (such as 50% of LEL or 2.5% by volume methane)
  - Some manufacturers provide a chart of Correction Factors in their manuals or in whitepapers. Typically the user multiplies the meter reading by the correction factor to get the actual reading for the gas being detected.
- Applying CFs electronically
  - Calibrate to a known concentration of gas (such as 50% of LEL or 2.5% by volume methane)
  - Libraries in the software of the monitor allow users to select a the gas being detected and the meter will automatically do the math to correct the meter reading to the correct scale

14502 Stetson Road, Los Gatos, CA 95033
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

Making LEL Decisions

It is difficult to make a decision with an LEL meter unless you know the scale in which you are measuring. The measurement scale is usually the calibration gas. Correction factors allow you to change scale without changing calibration gas.

Know your LEL meter measurement scale

Fire Dept. Changes Calibration Gas

A fire department was using an LEL sensor calibrated with n-pentane gas. But they found that their older LEL sensors sometimes didn't detect natural gas even when they were absolutely certain that natural gas was there. They switched from n-pentane in the cylinder to methane with a calibration factor on the side of the cylinder and found that they had much more reliability when looking to detect natural gas. N-pentane has an ignition temperature of just 500ºF (260ºC) compared with an ignition temperature of 999ºF (537ºC) for methane. As the catalyst aged, it was still able to catalyze the oxidation of n-pentane but it had lost the ability to catalyze the oxidation of methane.

Correction Factors Solve a Confined Space LEL Argument

A tank cleaning contractor had a slip/trip/fall injury in a chemical tank containing toluene vapors. The local HazMat team responded as part of the extrication team. The HazMat team argued that the contractor shouldn't have been in the tank because their meter showed a LEL reading of over 10% in the confined space. The contractor argued that their meter had a LEL reading of less than 10% so they were okay to enter the confined space. Further investigation showed that the HazMat team used a meter measuring in n-pentane which read 11% of LEL and the contractor used a meter measuring in methane with a reading of 6% of LEL. Let's review the facts:

- Tank contained Toluene
- HazMat Team meter readings:
  O_2: 20.9, LEL: 11, CO: ~20*, H_2S: 0
- Contractor meter readings:
  O_2: 20.9, LEL: 6, CO: ~20*, H_2S: 0, PID: 2640

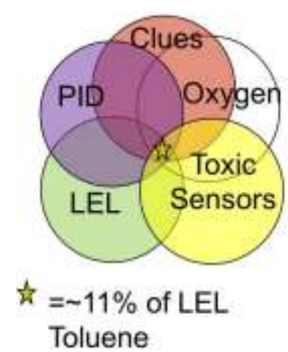
* Note that there probably wasn't any carbon monoxide (CO) in this space. Given the high concentration of Toluene in this space the CO reading is most likely due to the electrochemical CO sensors cross-sensitivity to Toluene.

It turns out that the HazMat team was using a meter that had a catalytic bead LEL sensor calibrated on a Pentane scale while the contractor was using a catalytic bead LEL sensor calibrated on a Methane scale that also included a PID. Using correction factors we can get to the root of the problem:

- HazMat Team:
  - $11\%LEL_{pentane} \times 1.06CF^{*}_{toluene} = 11.7\%LEL_{toluene}$
- Contractor:
  - $6\%\ LEL_{methane} \times 1.9CF^{*}_{toluene} = 11.4\%LEL_{toluene}$
- References:
  - $2640\ ppm_{iso} \times 0.5CF^{*}_{toluene} = 1320\ ppm_{toluene}$ or 11% of LEL
  - $100\%\ LEL_{toluene} = 1.2\%$ or $12{,}000\ ppm_{toluene}$
  - 10% of $LEL_{toluene} = 1{,}200\ ppm_{toluene}$

* Relative sensitivities are for example only; please consult your detector manufacturer for sensitivities specific to your product

So in this case the fire department and contractor meters were not set to the same "volume" or measurement scales. When the two meters were corrected to the same "volume" they both "heard" the vapors at the correct level. So both meters were initially wrong and then when corrected they were right and they agreed within the expected accuracy of these kinds of meters. Later we will talk about using Photoionization Detectors (PIDs) for LEL and we'll see that in this case the contractor has exceeded the PID 10% of LEL guideline number of 1000 ppm. But to be fair to the contractor this happened before the creation of the PID 10% of LEL guideline.

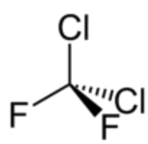


- **Clues:** tank cleaning with Toluene present
- **Oxygen**: 20.9%
- **Toxic Sensors:** Given the high concentration of toluene in this space the CO reading is most likely due to the electrochemical CO sensors cross-sensitivity to toluene
- **LEL:** both sensors were wrong and right until properly corrected
- **PID:** 2640 ppm isobutylene units exceeds 1000 ppm 10% of LEL guideline and is 11% LEL corrected

LEL Sensors Reads Freon

Workers who were removing Freon (R-12 or dichlorodifluoromethane) from a building HVAC system vented R-12 into the engineering space. One worker succumbed due to lack of oxygen and another was taken to hospital. The arriving HazMat team could see "shimmering" in the air when they made entry wearing PPE and SCBA. The oxygen levels on their meter dropped below 10%, PID read nothing but LEL reads as high as 12%. Once the area was ventilated and cleared of R-12 no other flammable gas was found to be present but the responders can't figure out the LEL sensor response because they couldn't find any "flammable" gas/vapor.

Even though R-12 does not have an LEL value, it still can provide a reading on a catalytic sensor because the carbon at the center of the molecule will burn. It won't read much; not all the way up to 100% LEL, but since it has carbon atoms it will burn some and cause a reading. This "frees" the halogens (Fluorine or "F" and Chlorine or "Cl" in the previous diagram where carbon or "C" is assumed to be in the middle) which then will corrode the sensor from the inside particularly if this is a chronic condition. This also can happen from vapors such as perchloroethylene, which also does not have an LEL and is considered non-flammable but contains carbon. Therefore it is advisable to limit the exposure of a catalytic bead LEL sensor to halocarbons. The fact that there was only 10% oxygen in the air shows that half of the air had been displaced by the R-12. Using the rule that every 0.1% in the oxygen reading means that 5000 ppm of something "else" is in the air we can see:

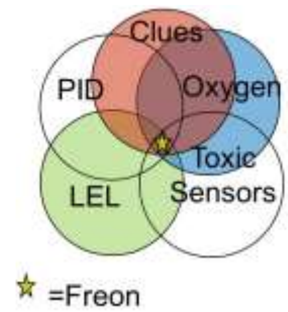


20.9-10 = 10.9 or 109 X 5000 = 545,000 ppm or 54.5% of R-12 in the air

A reading of 10% LEL to 12% LEL seems to be the highest reading R-12 may be able to reach. It would need to be over 100% LEL to be flammable, but a catalytic sensor can burn it enough to cause a slight reading.

- **Clues:** workers decommissioning an HVAC system
- **Oxygen:** as low as less than 10%
- **Toxic Sensors:** no change in readings
- **LEL:** as high as 12%, Freon has enough C in it to burn a little
- **PID:** no reading, even with natural gas and LP gas you would get a few hundred ppm from contaminants

Catalytic LEL Sensor Poisons



Common chemicals can degrade and destroy LEL sensor performance. Some of these poisons act very quickly or "Acutely" and some act over time or "Chronically." Some Acute Poisons include compounds containing:

- Silicone (firefighting foams, waxes)
- Lead (old gasoline)
- Phosphates and phosphorous
- High concentrations of combustible gas

Acute Poisoning Examples

- **Armor-All is not the Catalytic Bead Sensor's Friend**
  - A fire department complained about routine catalytic bead sensor failures
  - Investigation showed that the 4-gas monitor was stored on a clip next to a jump seat that was Armor-All'ed weekly
  - Armor-All doesn't only coat the seat, but it also coated the catalytic bead in the LEL sensor so gas couldn't get to the catalyst wire and it finally failed to work
- **LUST kills LEL sensors**
  - A contractor had the Orphan LUST (Leaking Underground Storage Tank) contract for the state of NJ. They were charged with removing and remediating old gasoline storage tanks that had been abandoned or "orphaned."
  - Their LEL sensors were only lasting 6 months
  - We found that the old tanks had gasoline remnants containing Tetra Ethyl Lead (TEL) which chemically poisoned the LEL sensor's catalyst
- **Monitor kills itself**
  - A gas detector manufacturer had a rash of LEL sensor failures
  - It was found that a display board that was made overseas had silicone caulk (RTV) on it to help keep the display from coming loose. The vendor sold this board to numerous

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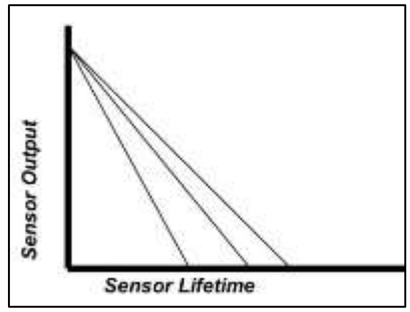
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

and various electronics manufacturers and all of them didn't care about the silicone caulk except for the gas detector manufacturer
    - The manufacturer worked with vendor to eliminate RTV from the display board
- **Deadly rubber mats**
    - A fire department complained of short LEL sensor life on the meters stored in their new HazMat rig
    - The detectors were stored on a rubber mat on top of a diamond plate storage cabinet
    - Silicone caulk was used to glue down rubber mat, it wept through the rubber mat and coated the catalytic bead so that gases/vapors couldn't permeate the bead to get to react with the catalyst.
    - Once the mat was removed and replaced and the silicone caulk was eliminated the sensor issues disappeared
- **The case of the killer case**
    - 4 gas monitor customer put their detector in a custom heavy duty, waterproof storage case
    - The customer made a custom foam insert to store everything neatly
    - The LEL sensor in the detector was not lasting long
    - Investigation determined that the custom foam was glued into the case with silicone caulk that was killing the LEL sensor in the tightly sealed case

With an "Acute" LEL sensor poison the sensor is going to fail, but the time to failure is dosage dependent.



Chronic Poisoning Examples

Chronic Poisons are often called "inhibitors" and act over time. Often exposure to clean air will allow the sensor to "burn-off" these compounds allowing the catalytic bead sensor to recover some response.

- Examples include:
    - Sulfur compounds (H_2S, CS_2)
    - Halogenated Hydrocarbons (Freons, trichloroethylene, methylene chloride)
    - Styrene
    - Carbonization: caused by the build-up of carbon on the surface of the catalyst when the concentration of combustible gas is allowed to remain high for too long
        - ✓ Basically it puts the catalyst in a "rich" environment and it coats the bead with carbon which prevents gas from getting to the catalyst
        - ✓ To help prevent this from happening, virtually all current LEL monitors automatically turn the sensor off when concentrations exceed 100% of LEL, although the meter remains in alarm
- **Styrene coats LEL sensor**
    - A styrene manufacturer couldn't get good life out of their LEL sensors
    - Styrene monomer polymerizes or hardens at about the same operating temperature of a LEL sensor (~250ºF/121ºC)
    - This coats the catalytic bead with a hard plastic shell that doesn't allow the catalyst to react with gases/vapors
    - Either use a different LEL technology (PID in this case) or periodically remove the meter from styrene

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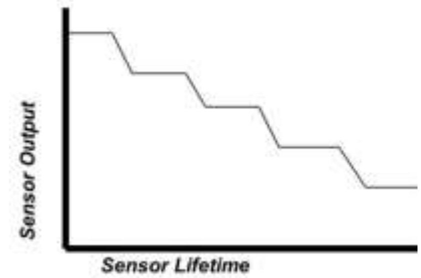
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

exposure so it burns off the accumulated styrene

- **You can calibrate too much**
  - A Superfund clean-up customer was calibrating three times a day because they wanted to guarantee the quality of their data which was to be used for litigation
  - But their LEL sensors were only lasting 1 year rather than 2 years as advertised and guaranteed by the manufacturer of their detector
  - The detector used calibration gas that had 25 ppm of H_2S in it so it could be used for bump testing and calibration. Using only 10 ppm may not pass a bump test because the gas could be 10% low and the sensor 10% low. Both would be within their accuracy specification but the detector would not give an alarm during its bump test.
  - But 25 ppm H_2S three times a day stressed the LEL sensor too much, switching to 10 ppm calibration gas solved the problem
- **Hot dogs kill LEL sensors**
  - The confined space monitor in a hot dog plant was only getting 6 months out of its LEL sensor
  - The "tubes" for the hot dog meat are made from edible rayon
  - Edible rayon is made by treating high grade wood pulp with CS_2 (Carbon Disulfide)
  - CS_2 is extremely capable at disabling catalytic beads. It is so capable that it is used by many testing labs as their standard for testing catalytic bead LEL sensors for resistance to poisoning.
  - Switching to another LEL detection technology was recommended because the plant wasn't about to change their process
  - PID was suggested as an alternative detector of flammability because it is resistant to CS_2 poisoning and it can also make toxicity decisions in atmospheres containing CS_2 (TWA = 20 ppm)
- **Pulp Mill Stink Kills LEL Sensors**
  - Pulp plant customer complains of getting short life out of their LEL sensors
  - The plant stinks with H_2S and mercaptans which are chronic LEL sensor toxins
  - PIDs are best for the turpentine areas but methane is present so PID can't do it alone
  - Could use NDIR and PID

With a "Chronic" LEL sensor poison the sensor recovers after an exposure, subsequent exposures will further degrade sensor output.



Wheatstone Bridge Catalytic Bead LEL sensors

<u>Advantages</u>

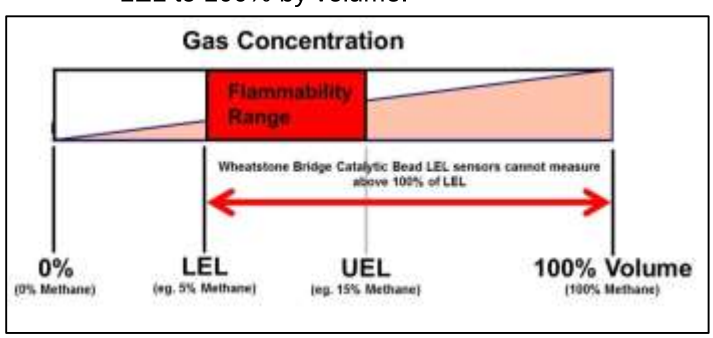
- ✚ Proven technology
- ✚ Direct measurement of flammability

<u>Disadvantages</u>

- − Can be poisoned
- − Cannot measure above 100% of LEL
- − Needs at least 12-16% oxygen for measurements
- − Difficulty measuring diesel, jet fuel, kerosene and similar vapors
- − Not sensitive enough for toxicity measurements

High Range Catalytic Bead Sensor Limitations

Traditionally, even with protective circuitry which protects the catalytic bead at concentrations above 100% LEL, catalytic bead sensors cannot read above 100% of LEL to 100% by volume.



While the catalytic bead sensor is the most common LEL sensor in handheld detectors, alternative techniques need to be considered

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610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

for high range combustible gas measurements. Some of these include:

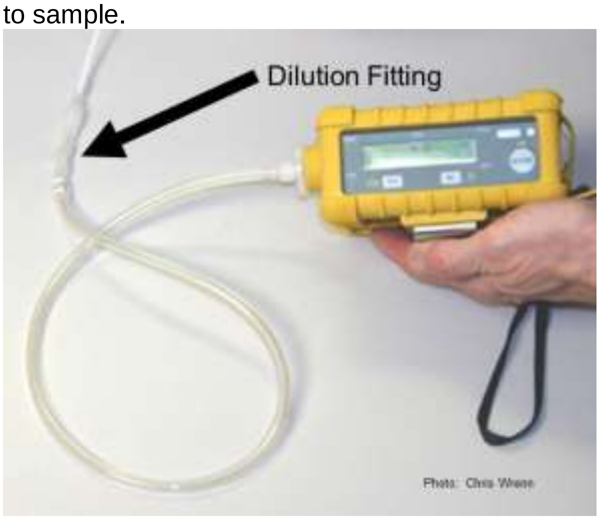
- Dilution fittings
- Calculation by means of oxygen displacement
- Thermal Conductivity (TC) sensors
- Non-dispersive Infrared (NDIR)

Dilution Fittings

Gas monitoring instruments can benefit from continuous sample dilution for several reasons including:

- Adding enough oxygen to inert sample gases to allow proper function of LEL and electrochemical sensors
- Bringing concentrated samples into the linear measurement range of the sensor
- Reducing humidity, methane, or other matrix gases that can affect the target gas readings
- Reducing possible damage to some sensors at high exposures

Dilution fittings usually attach between a length of sample hose and the meter, typically close to the meter. They assume that the user and the meter are in "fresh" air with 20.9% oxygen in it. Dilution fittings add a controlled amount of clean air to the sample mixture. For example it may be a 1 to 1 or a 10 to 1 dilution ratio of air to sample.



Some dilution fitting capable detectors automatically calculate the corrected reading accounting for the dilutant gas. This kind of capability is typically only found on high-end detectors.

Oxygen Sensors for LEL Decisions

LEL of methane is 5% by volume or 50,000 ppm. 50,000 ppm of methane will drop the oxygen sensors reading by 1%. At 100% of LEL methane (or 5% by volume) the oxygen level will only drop by 1% from 20.9% to 19.9% and the oxygen sensor will NOT be in alarm. 10% of LEL methane is just 5000 ppm, this will theoretically cause a drop in oxygen of 0.1% but due to detector dead-band (used to make the oxygen sensor appear more stable around 20.9%) users probably will not see this drop until 20.7%. At UEL of Methane (or 15% by volume) the oxygen level will be 17.9% and the oxygen sensor will be in alarm. Oxygen measurements are a crude LEL sensor but sometimes they are all we have particularly at concentrations above 100% of LEL into UEL levels. But as LEL goes up we should be noting that oxygen is going down. All our sensors should be working together when making gas detection decisions.

Remember that many LEL manufacturers recommend at least 12-16% oxygen for the proper performance of their catalytic bead LEL sensors

- The oxygen sensor will not be in alarm at LEL levels of common gases and vapors
- Even at UEL levels the oxygen sensor is JUST going into alarm for the vapors highlighted in orange

Gas/Vapor	LEL (% vol)	UEL (% vol)	Oxygen Reading at LEL	Oxygen Reading at UEL
Methane	5	15	19.9	17.9
Hydrogen	4	75	20.1	5.9
Propane	2	9.5	20.5	19
Gasoline	1.4	7.6	20.62	19.38
Acetone	2.2	12.8	20.46	18.34
Benzene	1.2	7.8	20.66	19.34
n-Pentane	1.5	7.8	20.6	19.34
MEK	1.8	11.4	20.54	18.62
Toluene	1.2	7.1	20.66	19.48
Diesel	0.8	10	20.74	18.9

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610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

How does Thermal Conductivity Work?

Thermal Conductivity (TC) sensors are commonly used by gas utility workers for their flammability decisions because of their very wide range of detection. While these workers need to stay at safe, they are not limited to staying below the LEL; they may even need to stay above the UEL to be safe. For example, when a big gas main leaks it may not be practical to shut down the main because all the downstream customers will have their gas turned off. When the gas turns back on there could numerous fire threats because of people who don't relight their pilot lights, filling their residences with flammable gas just waiting to find a source of ignition. In order to weld an active gas line, gas utility workers will check to see if their working environment is above the UEL and then weld up the hole in the gas main. As long as they stay above the UEL the spark from the welder will not ignite the gas.

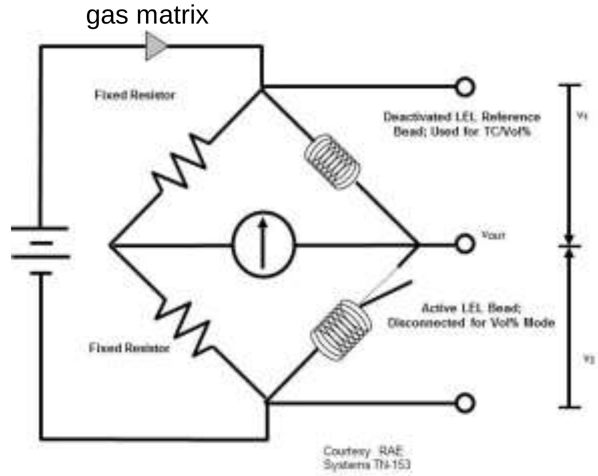
Air is about 20% Oxygen, 80% Nitrogen. Nitrogen does not conduct heat well. This is why down parkas keep us warm, the nitrogen in air retards heat transfer. Flammable gases conduct heat much better than nitrogen. As flammable gases replace nitrogen in a gas matrix, the matrix will be better at conducting heat. Were we to replace the nitrogen in our down parka with propane, not only will we become potentially flammable but we will not be warm either!

The Thermal Conductivity (TC) sensor operates on the principle of the cooling effect caused by the gas as it passes over a heated coil. Flammable gases tend to conduct heat better ("air conditioning") than nitrogen which is a great insulator. As the coil cools, the resistance decreases in proportion to the thermal conductivity of the gas.

Imagine a one burner electric stove. We set the stove to "Low" heat which uses a certain amount of power. As thermally conductive flammable gases replace the nitrogen in the atmosphere then more power will be required to keep the electric stove burner at "Low" heat. The more power required to keep maintain "Low" the more thermally conductive gas there is in the atmosphere.

Some manufacturers make combo TC/Vol sensors where the TC coil is part of a Wheatstone bridge that is integral to the LEL sensor.

- LEL: the coil acts as the reference bead and the catalytically active bead is connected to the bridge.
- TC/Vol: the active bead is disconnected and only the deactivated reference bead is used to measuring the cooling effect of gas matrix



Each type of gas has a unique TC and thus a unique relative response. The gas does not need to be combustible; it just needs to have a thermal conductivity that is different from the air matrix. No oxygen is required for its operation. Almost any gas can be measured as long as it has a different TC than the matrix gas. For example, CO_2 can be measured in air or H_2 in argon. The TC may be either higher or lower than that of the matrix gas. TC Sensors often display in % volume NOT % of LEL. 100% of LEL Methane is 5% by volume on a TC sensor. ***So if one is used to using catalytic bead LEL sensor, they would see 5% on the display of a meter and think that things are safe. But on a TC meter measuring methane, 5% represents 100% of LEL and a potentially flammable atmosphere.***

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Some TC Response Factors*

Gas/Vapor	Thermal Conductivity	Sensitivity (%)
Hexane	0.45	58
Butane	0.66	66
Argon	0.7	70
Carbon dioxide	0.7	70
Propane	0.7	70
Water	0.74	74
Acetylene	0.78	78
Ethylene	0.78	78
Ethane	0.9	90
Carbon monoxide	0.97	97
Air (reference)	1	100
Methane	1.45	145
Neon	1.87	187
Helium	5.5	550
Hydrogen	6.8	680

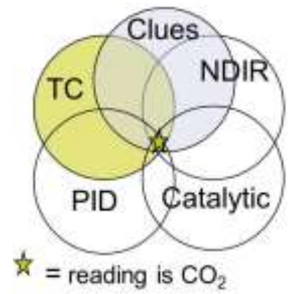
*These response factors are for example only, please consult your detector manufacturer for sensitivities specific to your product.

Natural Gas Detector Lies to a HazMat Team

EMS and a fire department engine company responded to a fast food restaurant where a pregnant woman fell. The woman said that she felt light headed and dizzy after going into a basement to get supplies. The fire department driver and officer went and checked out the basement and almost didn't get back up the steps because they were overcome by something in the atmosphere. Then HazMat responded. Wearing SCBA as they entered the basement, their meter showed low O_2, no LEL and no PID readings. Because they couldn't find anything in the basement's atmosphere they decided to try another meter. They got their natural gas detector off the rig and went back in the basement. It read high levels of flammable gas! Now they thought that they had a flammable atmosphere. But both the catalytic bead LEL and PID readings did not change and with both these sensors not changing at all this would indicate the absence of a potentially flammable atmosphere. Perhaps it had to do with the natural gas meter's TC sensor?

The cryogenic carbon dioxide (CO_2) tank in the basement of the fast food restaurant was leaking. The wall mounted CO_2 monitor was disabled. The TC natural gas meter was only designed for measuring natural gas, so it figured that the change in thermal conductivity was due to flammable gas because propane and CO_2 have the same thermal conductivity. But the real culprit was a leaking cryogenic CO_2 supply system.

- **Clues:** Slip trip and fall at fast food restaurant
- **NDIR:** no reading
- **Catalytic:** no
- **PID:** no reading
- **TC:** CO_2 leaking from cryogenic container fooled the TC sensor because CO_2 has about the same TC as propane
- **If the Catalytic bead AND PID don't show flammability it most likely isn't flammable**



TC sensors for Combustible Gases

<u>Advantages</u>

+ Great for high range measurements up to 100% by volume
+ Do not require oxygen

<u>Disadvantages</u>

− Secondary measurement (uses cooling affect)
− Other cooling gases in matrix can cause "false" alarms
− Less sensitive at low levels (0-10% of LEL)

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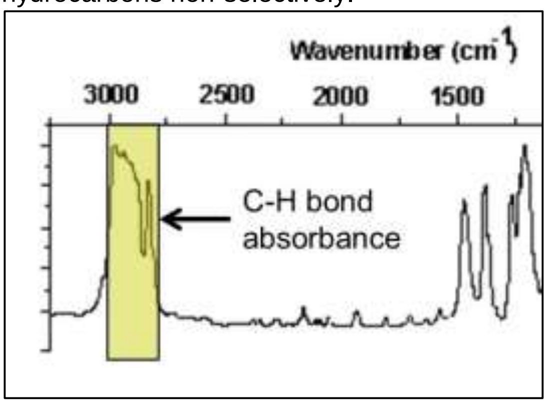
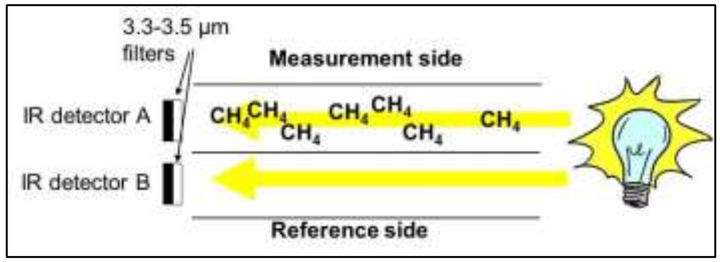
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

NDIR sensors for combustible gases

Non Dispersive InfraRed (NDIR) sensors use the absorption of infrared light to make gas measurements. Many molecules can absorb infrared light, causing them to bend, stretch or twist. The amount of InfraRed (IR) light absorbed is proportional to the concentration of flammable gas/vapor. The energy of the photons is not enough to cause ionization, and thus the detection principle is very different from that of a photoionization detector (PID). Ultimately, the energy is converted to kinetic energy, causing the molecules to speed up and thus heat the gas. C-H bonds (common to MANY BUT NOT ALL flammable hydrocarbon gases and vapors) absorb IR light in the range 3.3-3.5 µm (2800-3000 cm-1), depending on the structure of the rest of the molecule. Many compounds have similar C-H bonds and this absorbance is suitable to detect a range of hydrocarbons non-selectively.



Essentially the NDIR sensor looks for the shadows cast by C-H bonds when IR light is shined through gases/vapors with C-H bonds. Light passes through the gas sample and is absorbed in proportion to the amount of C-H bonds present. The more IR light absorbed the higher the concentration of C-H bonds. The filter in front of the detector removes all the light except that at 3.3-3.5 µm, corresponding to C-H bonds. A reference detector provides a real-time signal to compensate the variation of light intensity due to ambient or sensor changes. Without the reference detector the sensor would interpret a dimming lamp as an increase in hydrocarbon detection. But the reference detector signal compensates for these changes so that final concentration = Detector B – Detector A. Essentially the NDIR sensor looks for the "shadows cast" by C-H bonds when IR light is shined through gases/vapors with C-H bonds. The darker the shadow the higher the concentration.



NDIR LEL sensors will miss some flammable gases

Flammable gases and vapors that lack the C-H bond will not be seen by the NDIR LEL sensors. Some examples of flammable gases/vapors that NDIR LEL sensors miss:

- Hydrogen (H_2)
- Carbon Monoxide (CO)
- Ammonia, Phosphine (NH_3, PH_3)
- Carbon Disulfide (CS_2)

NOTE: NDIR can also be used for Carbon Dioxide (CO_2) measurements, BUT CO_2 absorbs at a different wavelength so NDIR dedicated to combustible gases will not work for CO_2

NDIR sensors for combustible gases

Advantages

- + Can measure to 100% by volume
- + Do not require oxygen
- + Resist poisons

Disadvantages

- − Secondary measurement (measures IR absorption of the C-H bond)
- − Misses some common combustible gases
- − Often more expensive

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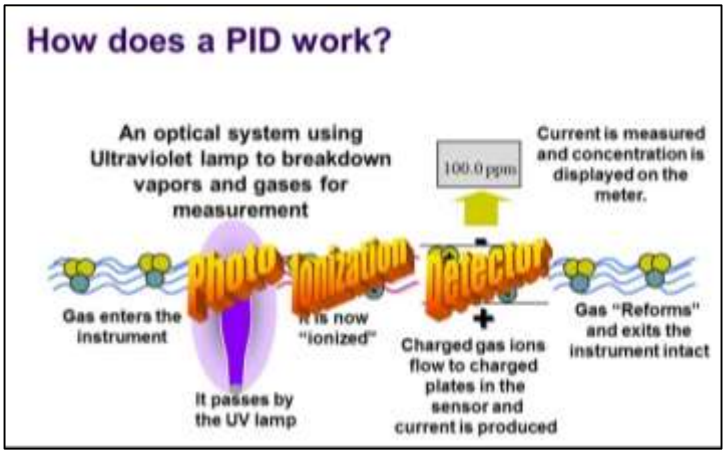
PIDs for Combustible Vapors

Photoionization Detectors (PIDs) detect VOCs in ppm (parts per million). Liquid hydrocarbon fuel product vapors are easily measured with a PID. A PID is a very sensitive broad spectrum monitor, like a “low-level LEL” detector. In a PID an ultraviolet (uV) light source breaks gases/vapors into ions that are counted in the detector. Gases and vapors with an ionization energy less than that of the uV light source will be ionized and counted in the detector.



Ionization Potential (IP)

IP determines if the PID can “see” the gas/vapor. If the IP of the gas/vapor is less than the eV output of the lamp the PID can “see” it. Think of the uV lamp in the PID like as a light bulb. *If the “wattage” of the gas or vapor is less than the “wattage” of the PID lamp then the PID can “see” the gas or vapor!* The most common uV lamp found in PIDs is a 10.6eV lamp which is appropriate for liquid hydrocarbon gas/vapor detection.

With a 10.6 lamp installed PIDs can measure:

- Organics: Compounds Containing Carbon (C)
  - Aromatics - compounds containing a benzene ring including benzene, ethyl benzene, toluene, xylene (BETX)
  - Ketones & Aldehydes - compounds with a C=O bond like acetone, MEK, acetaldehyde
  - Amines & Amides - Carbon compounds containing Nitrogen like diethyl amine
  - Chlorinated hydrocarbons like trichloroethylene (TCE)
  - Sulfur compounds like mercaptans, carbon disulfide
  - Unsaturated hydrocarbons - C=C & C C compounds like butadiene, isobutylene
  - Alcohol’s like ethanol (but not methanol because it isn’t ionizable with a 10.6ev lamp)
  - Saturated hydrocarbons like butane, octane
- Inorganics: Compounds without Carbon
  - Hydrides like ammonia and phosphine

PIDs don’t measure:

Methane, propane, ethane, hydrogen and methanol are some examples of flammable gases and vapors that have ionization potentials above the ionization capability of a PID so they will be unseen by a PID using the most common 10.6eV lamp.

Measuring LEL with a PID

PIDs measure in ppm and we’ve been talking about % of LEL and % Volume. In order to make LEL decisions with a PID we need to understand how to convert to ppm readings. If we multiply % Volume by 10,000 we get ppm. The LEL of gasoline is 1.2% by volume; multiplied by 10,000 we get 12,000 ppm. 10% of LEL Gasoline is 1200 ppm.

PIDs often are a better measurement tool for 10% of LEL for fuel and chemicals vapors & mists because catalytic sensors may have physical problems with these chemicals getting past their flame arrestor

What we can see from this chart is that when measuring on an isobutylene scale (the far

Chemical Name	LEL* (%vol)	LEL in PPM	10% of LEL in PPM	10% of LEL in Isobutylene units**
Acetone	2.5	25000	2500	2273
Gasoline	1.4	14000	1400	1647
MEK	1.4	14000	1400	1628
Styrene	0.9	9000	900	2250
THF	2	20000	2000	1111
Toluene	1.1	11000	1100	2200
Xylene	1.1	11000	1100	2558

* NFPA 325 "Guide to Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids, 1994 edition
** Divide ppm by the chemical correction factor for your PID

right column) 10% of LEL is always above 1000 ppm isobutylene units. This leads to the following guideline:

1000 ppm in Isobutylene units is a conservative measure of 10% of LEL for many common VOCs

- Always cross-reference catalytic bead LEL and PID for potentially flammable environments
- Always check catalytic bead LEL if you have a high PID reading, it could be a flammable environment, the catalytic bead LEL may need time to catch up
- Always check PID if you have a reading on the catalytic bead LEL. Even natural gas and LP ("Propane"), which because of their high ionization potentials one would think would not be seen with a PID, have enough contaminants that you'll see a few 100 ppm at 10% of LEL. This is because these mixtures are not pure methane or propane.
- If neither the catalytic bead LEL and the PID read anything, most likely a potentially flammable atmosphere is not present

When do I use PID for 10% of LEL?

- If you can see "it" like pouring it out of a can onto the ground then the PID is probably better
- If it is a gas that you can never "see" then the Wheatstone bridge catalytic bead sensor is better
- If the ionization potential of "it" is greater than 10.6eV then the Wheatstone bridge catalytic bead sensor is better for measurements even if it is a liquid that one can see (e.g. methanol)

PIDs for Combustible Gases/Vapors

Advantages

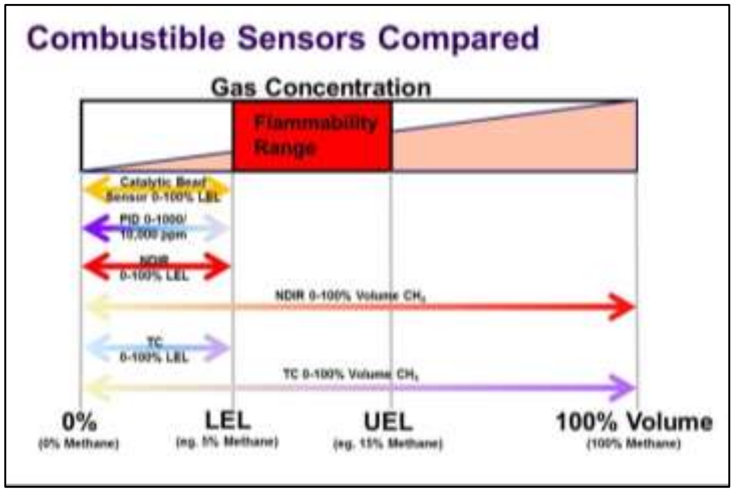
+ Easily measures "heavier" (low vapor pressure or high boiling point) chemical and fuel vapors
+ Resist poisons

Disadvantages

- Secondary measurement
- Misses common flammable gases like pure methane, propane, ethane, hydrogen and some common vapors like methanol
- More expensive

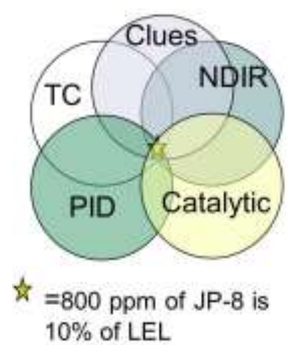
Combustible Sensors Compared

- 100% of LEL on catalytic bead sensor is 5% by volume on a TC sensor in methane
    - 5% of LEL is SAFE, so if you don't know that you are reading % volume you may mistakenly think you are safe
- 1000 ppm on PID ~ 10% of LEL



Wing tank LEL

When entering an aircraft wing tank, entrants can see and smell jet fuel but their catalytic LEL meters read nothing. While a primary detection of combustibility the flame arrestor in the catalytic bead gas sensor hinders the entrance of low vapor pressure chemicals like jet fuel into the sensor. Cold detectors will take time to warm up the thermal mass of the explosion-proof LEL sensor housing and this can impact response time for low vapor pressure chemicals. A manufacturer customized their detector with a 20 minute warm-up timer so the jet fuel had the best chance of getting to the LEL sensor without condensing on a cold explosion-proof sinter. Additionally, aircraft maintenance exposes catalytic bead sensors to poisoning silicone compounds. As a result of this, PIDs were selected for making LEL decisions in the wing tank entry application.

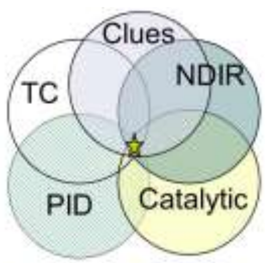


- **Clues:** wing tank containing jet fuel residue
- **NDIR:** good reading
- **Catalytic:** little or no reading, may take 20 minutes when it does respond
- **PID**: 800 ppm in jet fuel units is 10% of LEL
- **TC:** 10% of LEL too low to read

Pulp & Paper Turpentine LEL

An operator using a properly calibrated monitor did not measure flammable levels of turpentine but was severely burned in a turpentine flash during hot work. Because of its low vapor pressure the catalytic bead LEL sensor has great difficulty seeing turpentine and sulfur compounds in Pulp & Paper act as chronic poisons to LEL sensor that at its best can barely see turpentine. New monitors included both catalytic bead LEL and PID because other flammable gases like methane may be present that the PID cannot "see."

- **Clues:** turpentine recovery unit
- **NDIR:** good reading
- **Catalytic:** no reading for turpentine but required because methane may be present
- **PID:** 800 ppm in turpentine units or 10% of LEL but no methane reading
- **TC:** 10% of LEL too low to read

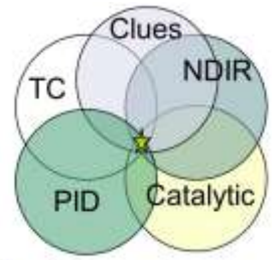


=800 ppm of Turpentine is 10% of LEL

Fuel Oil in the Basement

A fuel oil delivery truck mistakenly delivered to the wrong address. The wrong house had a disconnected oil fill tube because the house had been converted to natural gas. The driver "delivered" nearly 700 gallons before realizing that the house was only supposed to have a 250 gallon tank. The oil filled the basement and flowed into the sewers via a floor drain. Responders found pools of fuel oil in the basement with readings of about 250 ppm on their PID and nothing on LEL.

- **Clues:** pools of heating oil
- **NDIR:** good reading
- **Catalytic:** little or no reading, may take 20 minutes when it does respond
- **PID:** 250 ppm fuel oil units or 2.5% of LEL
- **TC:** 10% of LEL too low to read

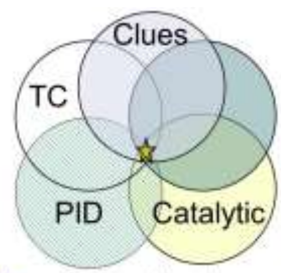


=250 ppm of fuel oil is ~2.5% of LEL

Sewer Investigation

A sewer authority needed to track down people dumping industrial chemicals in their sewer because the organic solvents were harming the digester at their treatment facility. This required entering the sewer to "sniff out" where the chemical was coming from. Investigators used a multi-sensor confined space monitor with catalytic bead sensor for the methane in the sewer and a PID to track or "sniff out" the organics.

- **Clues:** sewer investigation
- **NDIR:** good reading
- **Catalytic:** strong reading for methane no reading for the organics
- **PID:** strong reading for organics, no reading for methane
- **TC:** too low to read

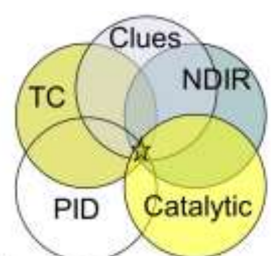


= Cat bead and PID work together

Natural Gas Well-head Monitoring

Operators need to test natural gas well-head for purity but they were also concerned about flammable levels of natural gas in their work area. They choose to use product with dual range catalytic/TC sensor.

- **Clues:** Natural gas well-head
- **NDIR:** good reading
- **Catalytic:** great for flammability in the area prior to sampling the well head but sampling the well-head over-ranges the sensor
- **PID:** no reading
- **TC:** perfect for the high-range purity reading



= Cat bead and TC work together

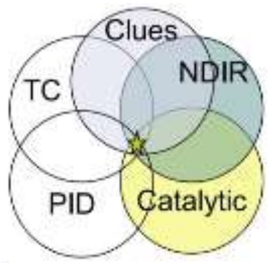
Antiperspirant Plant

Since halocarbons like "Freon" have been prohibited to use as a propellant an antiperspirant plant switched to flammable hydrocarbons like butane and octane. But

14502 Stetson Road, Los Gatos, CA 95033
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

this introduced the requirement for LEL detection in their work areas and confined spaces. Organic metallic antiperspirant compounds like aluminum chlorohydrate are acute poisons for the catalytic bead sensors. An NDIR sensor was recommended for LEL decisions because it could see the C-H bonds of butane and octane without being poisoned by the aluminum chlorohydrate.

- **Clues:** Antiperspirant plant with catalytic bead poisons as part of the process
- **NDIR:** good reading, good solution
- **Catalytic:** marginal, only lasts 3 months
- **PID:** no reading because the blowing agents are not ionizable
- **TC:** not sensitive enough

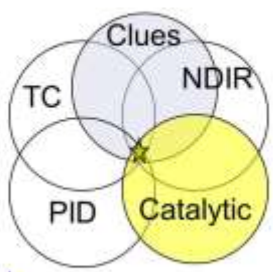


☆ = NDIR probably the best solution

Fire in Utility Cable Vault

Cables in an underground cable vault caught fire and burned. Oxygen in the vault was consumed by the fire and as it burned the vault atmosphere became highly saturated with carbon monoxide.

- **Clues:** fire in cable vault
- **NDIR:** no reading because CO had no C-H bond
- **Catalytic:** strong reading, may be over-ranged
- **PID:** no reading, CO isn't ionizable with PID
- **TC:** weak response because CO is only 3% different from air

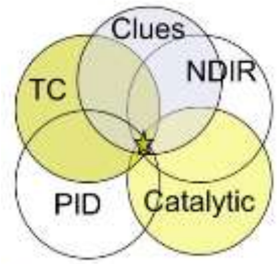


☆ = Cat bead is the only direct reading of flammability

Measuring Hydrogen at the Cape

NASA needed to measure hydrogen levels in an enclosed area that may need to be entered at Cape Kennedy. Hydrogen levels could be very high prior to entry which could be too high for the catalytic bead sensor.

- **Clues:** confined space containing hydrogen
- **NDIR:** no reading because H_2 has no C-H bond
- **Catalytic:** strong reading, may be over-ranged
- **PID:** no reading, H_2 isn't ionizable with PID
- **TC:** strong because TC is 680 times more sensitive to H_2 than air



☆ = TC is the way

Combustible Gas Sensors

- Only catalytic bead sensors are a primary measurement technology
- Know your measurement gas
- Watch out for catalytic bead sensor poisons
- All other combustible gas sensors will have "blind spots" to some classes of combustible gases
- Know your application and choose your sensors appropriately
- Catalytic bead and PID sensors are a great pairing for LEL measurements because they have complimentary "blind spots"
- ***When possible, multiple sensors can help your decision-making***

About the Author

Christopher Wrenn is the Vice President of Americas Sales for AEssense Corp., a Silicon Valley developer and manufacturer dedicated to providing innovative technological solutions for plant growers worldwide. Previously Chris was Sr. Director of Sales and Marketing for Environics USA, a provider of sophisticated gas & vapor detection solutions for the military, 1st responder, safety and homeland security markets. Chris was also a key member of the RAE Systems team, helping to grow RAE's revenues from $1M/yr to nearly $100M/yr in the above mentioned markets.

14502 Stetson Road, Los Gatos, CA 95033
610-659-4507, DetectionGeek.com, ChrisWrenn@att.net

Chris has extensive experience teaching gas and vapor detection and has been a featured speaker at more than 100 international conferences. He has written numerous articles, papers and book chapters on gas/vapor detection. Mr. Wrenn has received the following awards:

- 2011 “Outstanding Project Team Award,” in recognition of outstanding service and dedication to the Real Time Detection Registry Team presented by the AIHA (American Industrial Hygiene Association) President
- 2015, received the James H. Meidl “Instructor of the Year” award at The Continuing Challenge, Sacramento, CA presented by CA State Fire Marshal
- 2016, received the “Level A Award” from the International Hazardous Materials Response Team Conference “For your Leadership Service and Support to the Hazardous Response and Training Program.”

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