Real time detection of nitrogen dioxide:
Issues, concerns, setting alarms and interpreting data

Bob Henderson

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Robert E. Henderson

- Speaker Biography

Bob Henderson is the President of GfG Instrumentation, Inc., a leading supplier of portable and fixed gas detection products. GfG's instruments are used in atmospheric monitoring applications all over the world.

Robert has over 38 years of experience in the design, marketing and manufacture of gas detection instruments. Robert is a past Chairman, and in-coming Chair of the AIHA Real Time Detection Systems Technical Committee. He is also a past Chairman and current member of the AIHA Confined Spaces Committee. He is also a past Chair of the Instrument Products Group of the ISEA. Robert has a BS in biological science and an MBA from Rensselaer Polytechnic Institute.

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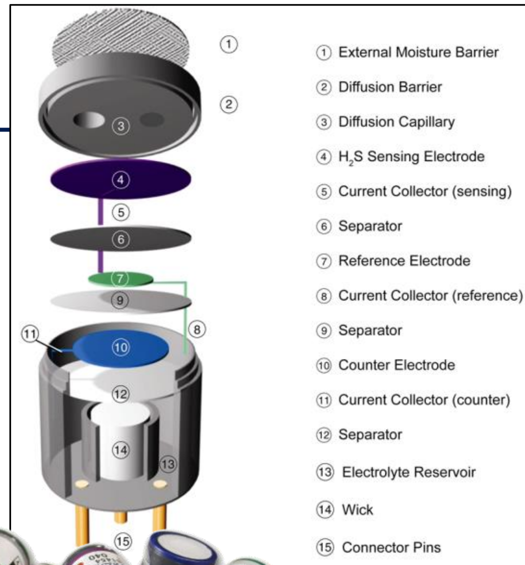
Substance-specific electrochemical sensors

- Gas diffusing into sensor reacts at surface of the sensing electrode
- Sensing electrode made to catalyze a specific reaction
- Use of selective external filters further limits cross sensitivity



Typical Electrochemical Detection Mechanism

H_2S Sensor:

Hydrogen sulfide is oxidized at the sensing electrode:

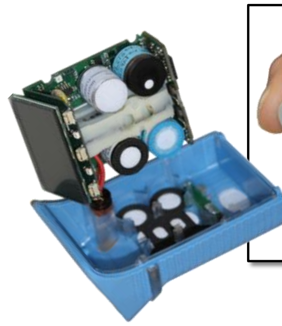
$$H_2S + 4H_2O \longrightarrow H_2SO_4 + 8H^+ + 8e^-$$

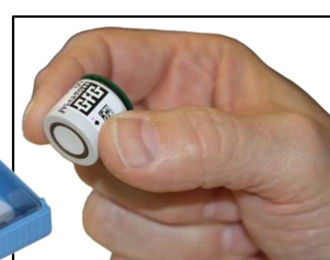
The counter electrode acts to balance out the reaction at the sensing electrode by reducing oxygen present in the air to water:

$$2O_2 + 8H^+ + 8e^- \longrightarrow 4H_2O$$

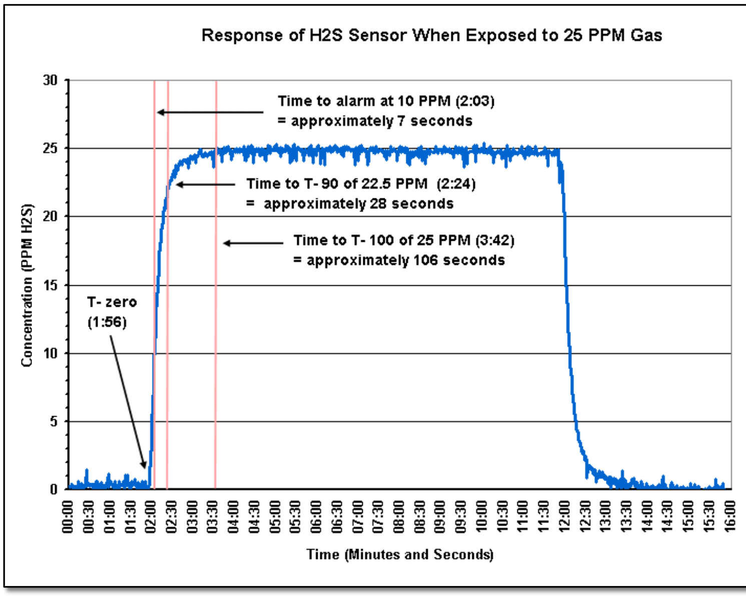
And the overall reaction is: $H_2S + 2O_2 \longrightarrow H_2SO_4$

City Technology 4HS Signal Output: 0.7 μ A / ppm H_2S





Electrochemical Sensor Performance



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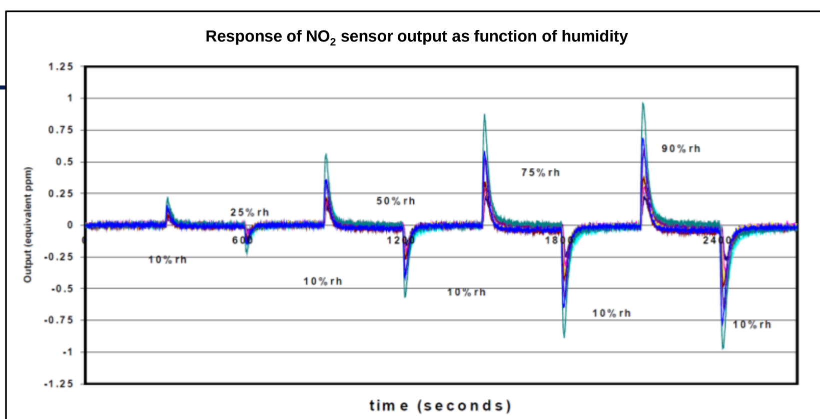
Effects of humidity on EC sensors



- Sudden changes in humidity can cause "transients" in readings
- Sensor generally stabilizes rapidly
- Avoid breathing into sensor or touching with sweaty hand

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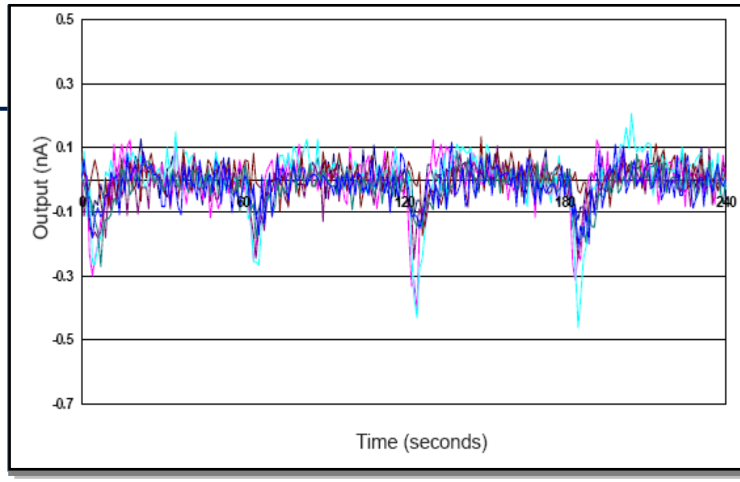
Signal to noise ratio of EC sensors

- Electrochemical amperometric gas sensors have a background current in addition to the current from the oxidation or reduction of the gas to be detected
- This background current is commonly referred to as zero current or "noise"
- Noise is random (stochastic) fluctuation of the electrical signal around a central value
- Noise is measured by the Root-Mean-Square (RMS) value of the fluctuations over time.
- The SNR is defined as the average over time of the peak signal divided by the RMS noise.
- When significant, can interfere with measurements at low gas concentrations.



Different sensors can have different performance characteristics

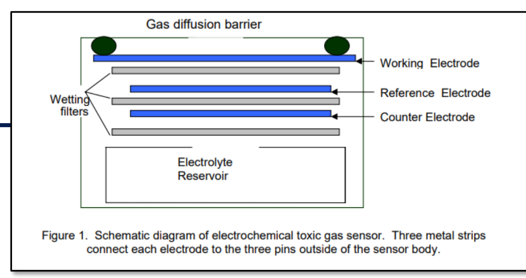


Figure 1. Schematic diagram of electrochemical toxic gas sensor. Three metal strips connect each electrode to the three pins outside of the sensor body.

Courtesy Alphasense

- Sources for zero current "noise" include:
  - Anodizing or cathodic reduction of the working electrode
  - Electrochemical oxidation or reduction of the sensor electrolyte
  - Electrolyte contamination by the working electrode
  - Reduction of oxygen in the ambient air
- Typical amperometric toxic gas sensor is three electrode design
  - The auxiliary (reference) electrode has the same catalyst structure as the working electrode but is not in contact with the measuring gas
  - By subtracting the current of the auxiliary electrode from the total current of the working electrode, noise is removed from the measurement signal
- Usability of sensor at low concentrations defined by RMS noise value
  - Some NO_2 sensors limited to 0.1 ppm
  - Some NO_2 sensors offer better resolution down to 0.05ppm or 0.02 ppm
  - More limited measurement range is often tradeoff for better resolution

Oxidizing vs. reducing gases

- Sensors for reducing gases:
  - Detection reaction generates current at working electrode; overall reaction consumes O_2
    - H_2S
    - CO
    - SO_2
    - PH_3
- Sensors for oxidizing gases:
  - Detection reaction consumes power at working electrode; overall reaction generates O_2
    - Cl_2
    - NO_2
    - O_3
    - HCl
    - HF
    - ClO_2

Oxidizing gas sensor detection reaction

- Chlorine sensor detection reaction:
  - Sensing electrode:

    $Cl_2 + 2e^- \longrightarrow 2Cl^-$
  - Counter electrode:

    $½\,O_2 + 2H^+ + 2e^- \longrightarrow H_2O$
  - Overall:

    $Cl_2 + H_2O \longrightarrow 2Cl^- + ½O_2 + 2H^+$

- Nitrogen dioxide detection reaction:
  - Sensing electrode:

    $NO_2 + 2H^+ + 2e^- \longrightarrow NO + H_2O$
  - Counter electrode:

    $½\,O_2 + 2H^+ + 2e^- \longrightarrow H_2O$
  - Overall:

    $NO_2 \longrightarrow NO + ½\,O_2$

Select performance characteristics typical electrochemical SO_2 sensor at 20°C

Signal: 0.5 ± 0.1 µA/ppm

Linear signal over wide range:

- 0.1 µA = 0.2 ppm
- 1.0 µA = 2.0 ppm
- 4.0 µA = 8.0 ppm

Measurement range: 0-20 ppm SO_2

Resolution (electronics dependent): 0.1 ppm

Response Time (T_{90}): < 25 seconds

Relative responses of City Technology 4S – Rev. 2 sulfur dioxide (SO_2) sensor at 20°C

Gas	*Concentration used (ppm)*	*Reading (ppm SO2)*
Carbon monoxide (CO)	*300*	*< 1*
Nitric oxide (NO)	*50*	*0 to 5.0*
Nitrogen dioxide (NO_2)	*6*	*< −10*
Hydrogen sulfide (H_2S)	*25*	*< 0.1*
Chlorine (Cl_2)	*5*	*< −2*
Ammonia (NH_3)	*20*	*0*
Hydrogen (H_2)	*400*	*< 1*
Hydrogen cyanide (HCN)	*10*	*< 5*
Acetylene (C_2H_2)	*10*	*< 30*
Ethene (C_2H_4)	*50*	*< 45*

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Select performance characteristics typical electrochemical NO_2 sensor at 20°C

Sensoric 4ND Citicel is three electrode design

Linear signal: 0.60 ± 0.15 mA/ppm

Measurement range: 0-20 ppm NO_2

Resolution (electronics dependent): 0.1 ppm

- 0.012 µA = 0.02 ppm
- 0.03 µA = 0.05 ppm
- 0.06 µA = 0.1 ppm

Response Time (T_{90}): < 25 seconds

What about ozone?

- Not listed on sensor data sheet
- But interferes strongly (about 1.2)
- Equivalent concentration O_3 produces higher reading than NO_2

Relative responses of Sensoric 4ND CiTiceL NO2

Gas	Concentration used	Reading (ppm NO_2)
Alcohols	1000	0
Carbon dioxide	5000	0
Chlorine	1	1
Nitric oxide (NO)	100	0.4
Sulfur dioxide (SO_2)	20	-5
Hydrogen	3000	0

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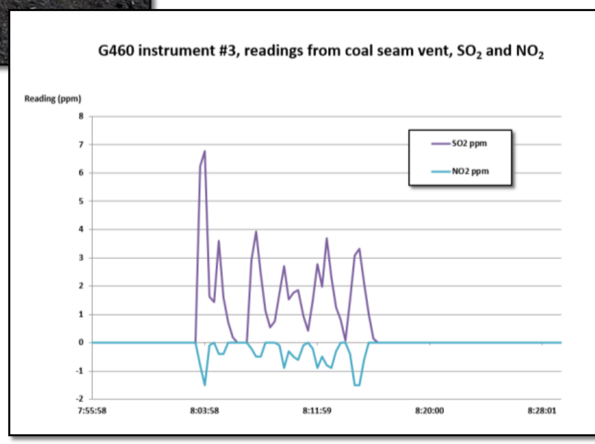
Be aware of potential cross sensitivity issues!

- Incompatibility issues may make calibration difficult or impossible
- Sometimes better to install incompatible sensors in different instruments



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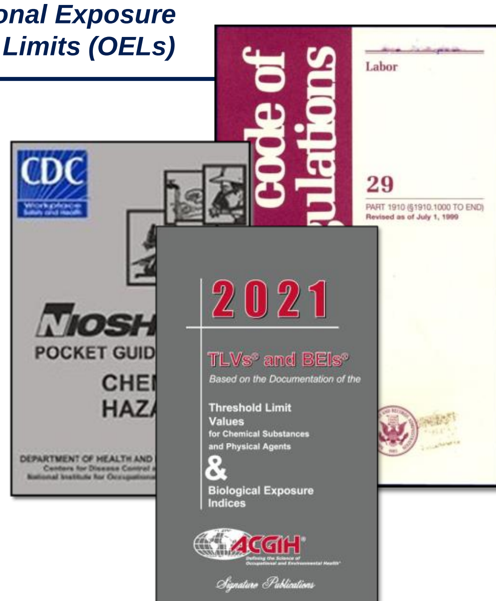
Occupational Exposure Limits (OELs)

- Depend on jurisdiction and activity
- Sets limits for <u>unprotected</u> worker exposure to a listed toxic substance
- Limits for gases and vapors given in “Parts-per-Million” (ppm) concentrations
- Do not provide direct guidance for how to set instrument alarms!



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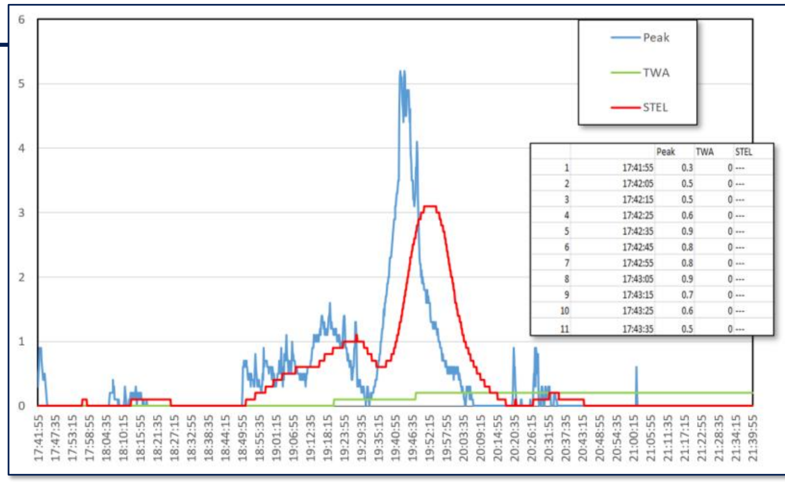
Typical alarms in personal and multi-sensor gas detectors

- Gas alarms settable by user:
  - Peak (instantaneous) Low
  - Peak (instantaneous) High
  - STEL (15 minute)
  - TWA (8 hour)
- Non-user settable alarms:
  - Over limit concentration
  - Negative alarm
- Sometimes settable by user:
  - Measuring range
  - Resolution



		Peak	TWA	STEL
1	17:41:55	0.3	0	---
2	17:42:05	0.5	0	---
3	17:42:15	0.5	0	---
4	17:42:25	0.6	0	---
5	17:42:35	0.9	0	---
6	17:42:45	0.8	0	---
7	17:42:55	0.8	0	---
8	17:43:05	0.9	0	---
9	17:43:15	0.7	0	---
10	17:43:25	0.6	0	---
11	17:43:35	0.5	0	---

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Exposure limits for NO_2

- US OSHA PEL:

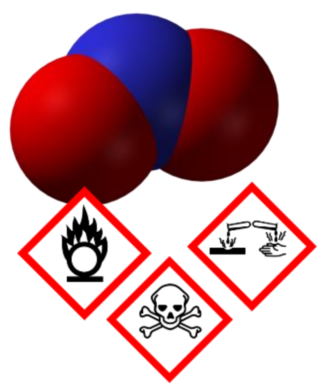
  Ceiling = 5 ppm
- US NIOSH REL:

  15 min. STEL = 1.0 ppm
- Old TLV:

  8 hr. TWA = 3.0 ppm

  5 min. STEL = 5.0 ppm
- New 2012 TLV

  8 hr. TWA = 0.2 ppm



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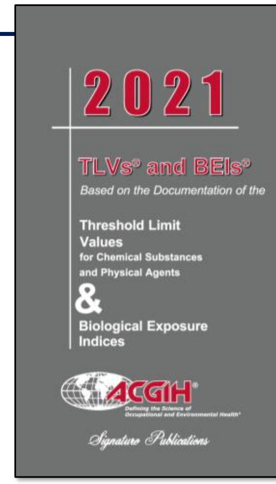
ACGIH Guidance



For many substances with a TLV–TWA, there is no TLV–STEL.

Never-the-less, short-term peak exposures above the TLV–TWA should be controlled, even where the 8-hour TLV–TWA is within recommended limits.

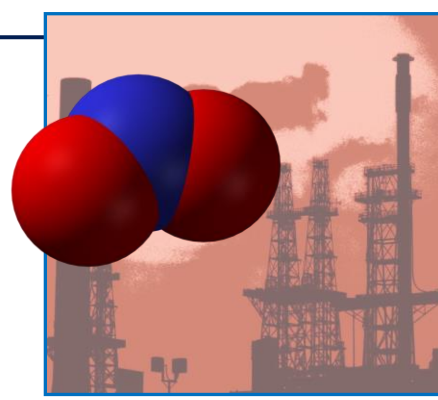
The following default short-term exposure limits apply to those TLV–TWAs that do not have a TLV–STEL:

> Transient increases in workers' exposure levels may exceed 3 times the value of the TLV–TWA level for no more than 15 minutes at a time, on no more than 4 occasions spaced 1 Hour apart during a workday, and under no circumstances should they exceed 5 times the value of the TLV–TWA level when measured as a 15-min TWA.
>
> In addition, the 8-hour TWA is not to be exceeded for an 8-hour work period.

This guidance on limiting peak exposures above the value of the TLV–TWA is analogous to that for the TLV–STEL, and both represent 15-minute exposure limits.

Suggested alarm settings for NO_2

- Suggested alarms:
  - OSHA PEL or NIOSH REL:
    - Low: 3.0 ppm
    - High: 5.0 ppm
    - STEL: 1.0 ppm
    - TWA: 1.0 ppm
  - TLV®:
    - Low: 0.6 ppm
    - High: 1.0 ppm
    - STEL: 0.6 ppm
    - TWA: 0.2 ppm



What should you do for extended work shifts?

- Most industrial hygienists use Brief and Scala model
  - Corrects for increased exposure time and decreased recovery time
  - Simple to use
  - Very conservative
- Adjusted TLV =

$$= \text{TLV} \times \frac{(8)}{h} \times \frac{(24 - h)}{16}$$

Where h = # of hours worked per day

- Model used for chemicals where the TLV® is based on acute or chronic toxicity and <u>not</u> for chemicals that have a TLV® based on irritation (i.e. Ammonia)
- For 12 hour shift according to this model the TWA TLV® limit should be reduced to one-half the 8-hour value

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Datalogging parameters

- Number of stored intervals in internal memory – set by manufacturer
- Datalogging interval (generally 1 sec. to 1 hr.)
- Logged values per interval (typically):
  - User choice:
    - Peak
    - Average
    - Representative
  - STEL
  - TWA
- How are the time history alarm calculations affected by the choice of data-logging interval?
  - They're not!
  - PEL calculations are continuously updated by the instrument
  - The datalogging interval simply specifies how often the instrument stores a "snap-shot" of the current readings for the purposes of generating a printed report or database file of test results

		Peak	TWA	STEL
1	17:41:55	0.3	0	---
2	17:42:05	0.5	0	---
3	17:42:15	0.5	0	---
4	17:42:25	0.6	0	---
5	17:42:35	0.9	0	---
6	17:42:45	0.8	0	---
7	17:42:55	0.8	0	---
8	17:43:05	0.9	0	---
9	17:43:15	0.7	0	---
10	17:43:25	0.6	0	---
11	17:43:35	0.5	0	---
12	17:43:45	0.4	0	---
13	17:43:55	0.5	0	---
14	17:44:05	0.4	0	---
15	17:44:15	0.5	0	---
16	17:44:25	0.4	0	---
17	17:44:35	0.3	0	---
18	17:44:45	0.2	0	---
19	17:44:55	0.1	0	---
20	17:45:05	0	0	---
21	17:45:15	0	0	---
22	17:45:25	0	0	---
23	17:45:35	0	0	---
24	17:45:45	0	0	---
25	17:45:55	0	0	---
26	17:46:05	0	0	---
27	17:46:15	0	0	---
28	17:46:25	0	0	---
29	17:46:35	0	0	---
30	17:46:45	0	0	---
31	17:46:55	0	0	---
32	17:47:05	0	0	---
33	17:47:15	0	0	---
34	17:47:25	0	0	---
35	17:47:35	0	0	---
36	17:47:45	0	0	---
37	17:47:55	0	0	---
38	17:48:05	0	0	---
39	17:48:15	0	0	---
40	17:48:25	0	0	---
60	17:51:45	0	0	---
61	17:51:55	0	0	---
62	17:52:05	0	0	---
63	17:52:15	0	0	---
64	17:52:25	0	0	---
65	17:52:35	0	0	---
66	17:52:45	0	0	---
67	17:52:55	0	0	---
68	17:53:05	0	0	---
69	17:53:15	0	0	---
70	17:53:25	0	0	---
71	17:53:35	0	0	---
72	17:53:45	0	0	---
73	17:53:55	0	0	---
74	17:54:05	0	0	---
75	17:54:15	0	0	---
76	17:54:25	0	0	---
77	17:54:35	0	0	---
78	17:54:45	0	0	---
79	17:54:55	0	0	---
80	17:55:05	0	0	---
81	17:55:15	0	0	---
82	17:55:25	0	0	---
83	17:55:35	0	0	---
84	17:55:45	0	0	---
85	17:55:55	0	0	---
86	17:56:05	0	0	---
87	17:56:15	0	0	---
88	17:56:25	0	0	---
89	17:56:35	0	0	---
90	17:56:45	0	0	0.1
91	17:56:55	0	0	0.1
92	17:57:05	0	0	0.1
93	17:57:15	0	0	0.1
94	17:57:25	0	0	0.1
95	17:57:35	0	0	0.1

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So how accurate are the readings?

- Instrument manufacturers frequently state accuracy of +/- 5% of readings
- NO_2 sensor measurement range is typically 0 – 20 ppm
- If the instrument is set to display readings in ± 0.1 ppm increments:
  - From 0 – 2.0 ppm the accuracy is +/- 0.1 ppm, from 2.0 to 20 ppm the accuracy is +/- 5% of reading
- If the instrument is set to display readings in ± 0.02 ppm increments:
  - From 0 – 0.4 ppm the accuracy is +/- 0.02 ppm, from 0.4 to 20 ppm the accuracy is +/- 5% of reading
- What about designs that digitally filter readings near zero?
  - Some instruments have a “dead band” or digital filtering to reduce fluctuation in readings near zero
  - Affects visible readings but not the time history calculations or logged Peak values
  - Some designs introduce digital stickiness near zero, which decreases as measurement values rise, other designs use a dead-band that shows a reading of zero throughout the band
    - For instance, if the instrument resolution is 0.1 ppm and has a dead-band of +/-0.2 ppm, (two steps away from zero) visible readings will show 0 ppm whenever the signal is within this band, and the first visible reading above zero would be 0.3 ppm

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How does the accuracy of the cal gas affect the accuracy of the readings?

- Standard NO_2 cal gas with 10 ppm NO_2 is available with ± 3% accuracy, 12-months shelf-life dating
- Using ± 3% accuracy gas, when the resolution of the NO_2 sensor is 0.1 ppm, the new accuracy statement for the combined instrument and cal gas system becomes 0.1 ppm or ± 8% of reading, whichever is greater
  - So from 0 – 1.25 ppm the accuracy is ± 0.1 ppm
  - From 1.25 – 20.0 ppm the accuracy is ± 8% of reading
- When the resolution of the NO_2 sensor is 0.02 ppm
  - From 0 – 0.25 ppm the accuracy is ± 0.02 ppm
  - From 0.25 – 20.0 ppm the accuracy is ± 8% of reading

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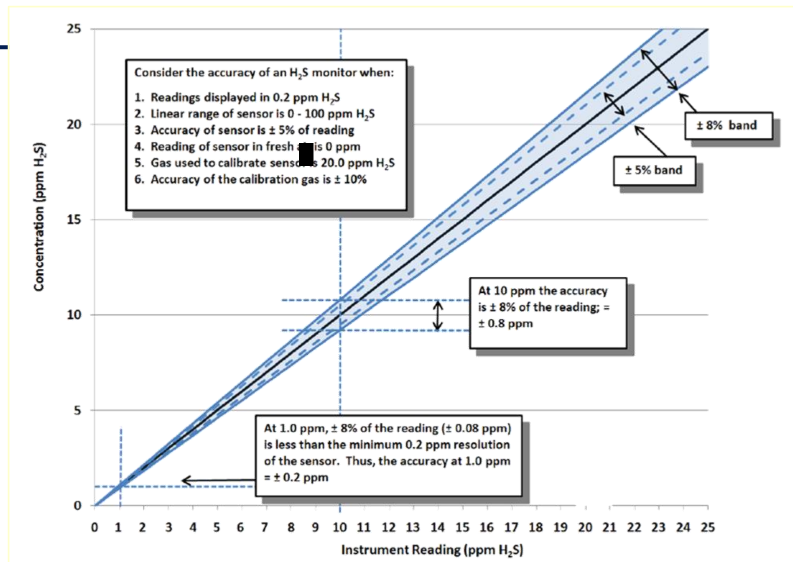
Combined effects of sensor and calibration gas accuracy

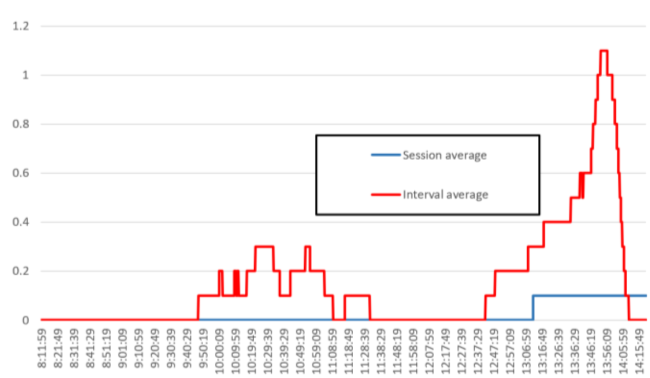


Instrument A: Single-sensor personal NO_2 datalogger

- Session duration: ~ 6.4 hr.
- Low alarm: 3.0 ppm
- High alarm: 5.0 ppm
- STEL: 1.0 ppm
- TWA: 0.2 ppm
- Peak reading during session: 2.4 ppm
- Session duration: 6.39 hrs.
- Datalogging interval: 10 sec.
- Session average (TWA): 0.1 ppm

Session Download for Instrument A
Start session: 6/12/2019 7:56:59 AM
End session: 6/12/2019 2:20:09 PM

Summary	
Unit Name	
Unit SN	
Unit Firmware Ver	V1.80A
Running Mode	Safety Mode
Measure Type	Real
Datalog Mode	Continuous
Datalog Type	Auto
Diagnostic Mode	No
Stop Reason	Pause in Communication Mode
Site ID	SITE0000
User ID	USER0000
Begin	6/12/2019 7:56
End	6/12/2019 14:20
Sample Period(s)	10
Number of Records	2299
Sensor	NO2(ppm)
Span	5
Span 2	N/A
Low Alarm	3
High Alarm	5
Over Alarm	20
STEL Alarm	1
TWA Alarm	0.2
Measurement Gas(CF)	N/A
Calibration Time	6/9/2019 14:38
Peak	2.4
Min	0
Average	0.1



The highest "Peak" reading for the session is recorded separately in the "summary" chart. The data table records the average reading for each 10 second interval. "Peak" readings for each interval are not recorded in the data table. According to the "summary" chart the highest "Peak" reading reached during the session was 2.4 ppm. The highest 10 sec. interval average recorded was 1.1 ppm. The average for entire session was 0.1 ppm. The minimum value recorded was zero. If there were any negative values they were not recorded. There is nothing in the data table to identify exactly when the 2.4 ppm "Peak" was reached.

Time	Session average	Interval average
13:52:09	0.1	1
13:52:19	0.1	1
13:52:29	0.1	1.1
13:52:39	0.1	1.1

Instrument B: Multi-sensor instrument with O_2, CO, H_2S, NO_2 and SO_2 sensors

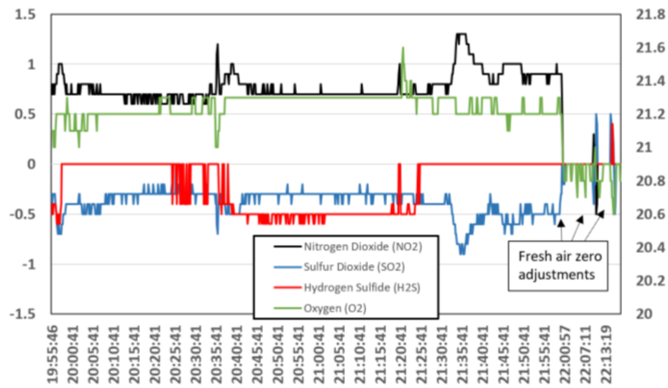
- Session duration: 6.39 hrs.
- Datalogging interval: 10 sec.

- NO_2 Low alarm: 3.0 ppm
- NO_2 high alarm: ?
- STEL alarm: 1.0 ppm
- TWA alarm: ?
- TWA actual: 0.2 ppm
- Highest NO_2 peak reading during session: 1.3 ppm

- SO_2 low alarm: 2.0 ppm
- SO_2 high alarm: ?
- STEL alarm: 0.25
- SO_2 TWA alarm: ?
- TWA actual: 0 ppm
- Highest NO_2 peak reading during session: 0.5 ppm

NO2	
TWA (8Hr)	0.2
Max Peak	1.3
Max STEL	1.02
Count Peak Interval Alarms>3ppm	0
Count STEL Alarms>1ppm	22
SO2	
TWA (8Hr)	0
Max Peak	0.5
Max STEL	0.02
Count Peak Interval Alarms>2ppm	0
Count STEL Alarms>0.25ppm	0
CO	
TWA (Hr)	0
Max Peak	0
Max STEL	0
Count Peak Interval Alarms>25ppm	0
Count STEL Alarms>50ppm	0
H2S	
TWA (Hr)	0
Max Peak	0.4
Max STEL	0.01
Count Peak Interval Alarms>7.5ppm	0
Count STEL Alarms>5ppm	0
O2	
Max Peak	21.6
Min Peak	20.6
Average O2 Level	21.2
Count MaxPeak Interval Alarms>23.5ppm	0
Count MinPeak Interval Alarms>19.5ppm	0

Instrument B - Multi-sensor instrument equipped with O2, CO, H2S, NO2 and SO2 sensors
Start session June 19, 1919 7:55 PM
End session June 19, 1919 10:17 PM



Datalog interval was 10 seconds. Logged value is average reading during each 10 second interval. Initial O_2 reading shows instrument was not fresh air adjusted at startup. O_2 reading was 21.2% -22.3% for most of session. It looks like instrument was fresh air adjusted around 10:00:01 PM, resetting the NO_2 and SO_2 readings to 0 ppm, and resetting the NO_2 STEL calculation to 0 ppm. Since SO_2 readings were negative for most of the session, the SO_2 STEL calculation was 0 ppm both before and after the fresh air zero. It appears the instrument was zeroed while still in the presence of NO_2 gas. Later, the NO_2 reading went negative and the SO_2 sensor went positive as the sensors stabilized in air that contained less NO_2. It appears that the instrument was fresh air zeroed again about 10:10:40 and again at 10:11:22.

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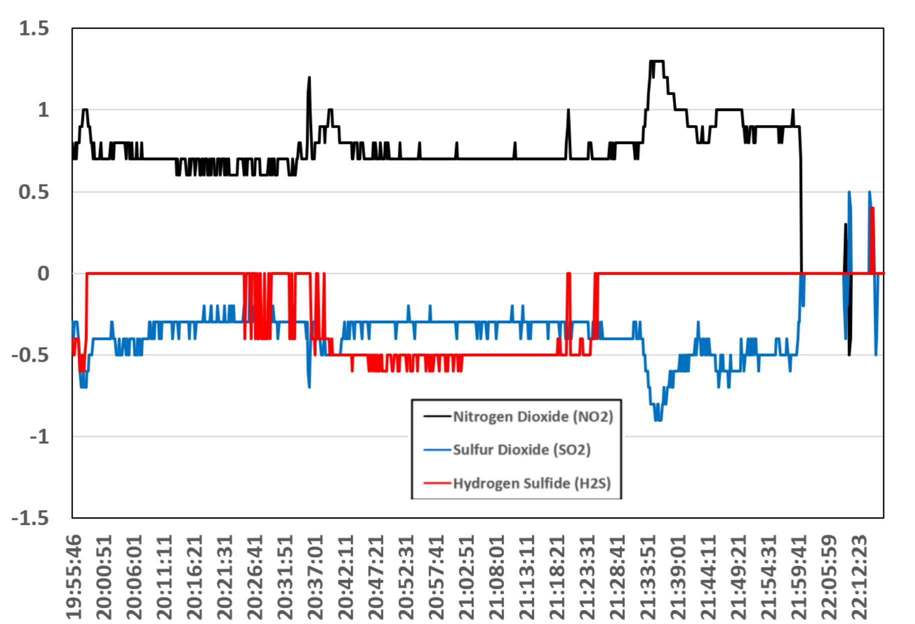
Instrument B: Multi-sensor instrument with O_2, CO, H_2S, NO_2 and SO_2 sensors

- SO_2 has strong negative interference to NO_2 of about -0.6
- Response of NO_2 and SO_2 sensors mirror each other
- H_2S readings not affected by NO_2
- Negative H_2S readings probably due to sensor needing fresh air adjustment
- True H_2S concentration probably about 0.4 ppm



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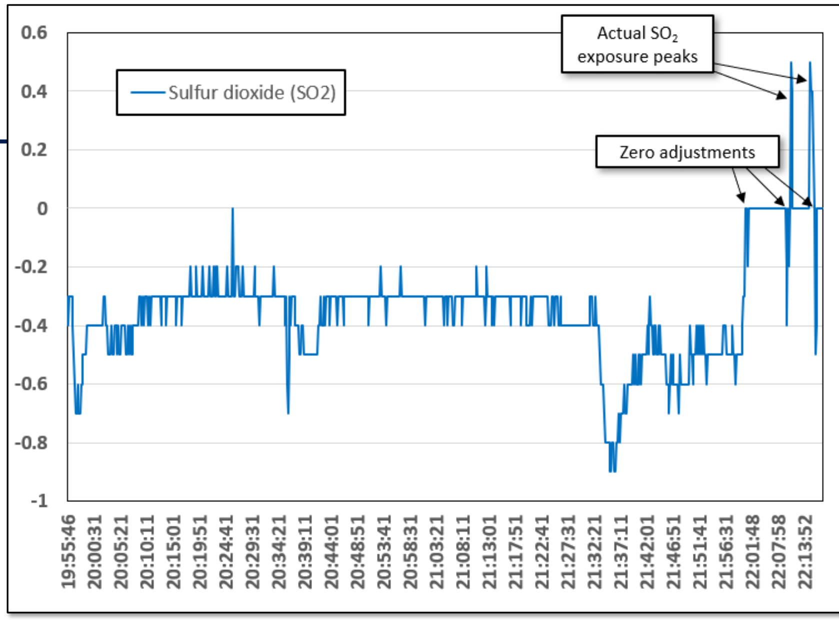
Instrument B: Multi-sensor instrument with O_2, CO, H_2S, NO_2 and SO_2 sensors

- *Chart shows results for SO_2 only*
- *SO_2 readings were negative for most of session because of presence of NO_2 gas*
- *The SO_2 sensor (along with the other sensors) was zero adjusted three times at 22:00, 22:09 and 22:17 in the probable presence of about 0.5 ppm SO_2 gas.*



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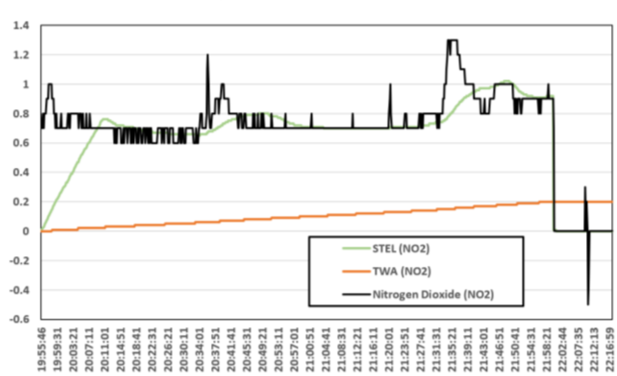
Instrument B: Multi-sensor instrument with with O2, CO, H_2S, NO_2 and SO_2 sensors

- NO_2 results (actual logged, STEL and TWA)
- Low alarm: 3.0 ppm
- High alarm: ?
- STEL alarm: 1.0 ppm
- TWA alarm: ?
- TWA (projected): 0.2 ppm
- Peak reading during session: 2.4 ppm
- Session duration: 6.39 hrs.
- Session average: 0.1 ppm

Instrument B - Multi-sensor instrument equipped with O2, CO, H_2S, NO_2 and SO_2 sensors
Start session June 19, 1919 7:55 PM
End session June 19, 1919 10:17 PM

NO2	
TWA (8Hr)	0.2
Max Peak	1.3
Max STEL	1.02
Count Peak Interval Alarms>3ppm	0
Count STEL Alarms>1ppm	22
SO2	
TWA (8Hr)	0
Max Peak	0.5
Max STEL	0.02
Count Peak Interval Alarms>2ppm	0
Count STEL Alarms>0.25ppm	0
CO	
TWA (Hr)	0
Max Peak	0
Max STEL	0
Count Peak Interval Alarms>25ppm	0
Count STEL Alarms>50ppm	0
H2S	
TWA (Hr)	0
Max Peak	0.4
Max STEL	0.01
Count Peak Interval Alarms>7.5ppm	0
Count STEL Alarms>5ppm	0
O2	
Max Peak	21.6
Min Peak	20.6
Average O2 Level	21.2
Count MaxPeak Interval Alarms>23.5ppm	0
Count MinPeak Interval Alarms>19.5ppm	0



Summary table shows results for all installed sensors. Chart shows results for NO_2 only. Datalog interval was 10 seconds. Logged NO_2 value was the average reeading during each 10 second interval. The "MAX PEAK" value of 1.3 ppm in the summary table is logged and retained separately. There is a discontinuity in the logged STEL values around 10:00:01 PM. It looks like the instrument was zeroed at that time, resetting the NO_2 reading to 0 ppm, and resetting the STEL calculation to 0 ppm. The TWA calculation was not reset. It appears the instrumennt was zeroed while still in the presence of NO_2 gas. Later, the NO_2 reading went negative as the sensor stabilized in air that contained less NO_2. It appears that the instrument was fresh air zeroed again about 10:10:50. The SO_2, H_2S and O_2 readings (which for simplicity are not shown on the chart) were affected by these fresh air

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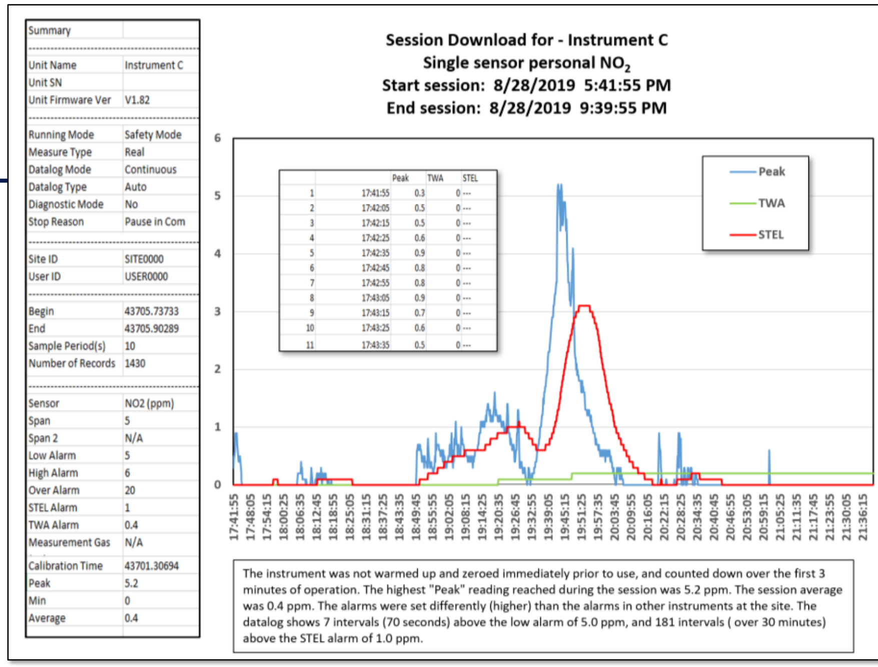
Instrument C: Single-sensor personal NO_2 datalogger

- Session duration: 4 hours
- Datalogging interval: 10 sec.
- Low alarm: 5.0 ppm
- High alarm: 6.0 ppm
- STEL alarm: 1.0 ppm
- TWA alarm: 0.4 ppm
- Peak reading during session: 5.2 ppm
- Session duration: ~4 hrs.
- Session average (TWA): 0.2 ppm



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Important problem: Instrument NO_2 alarms inconsistent!

	Resolution	Low	High	STEL	TWA
Instrument A	0.1 ppm	3.0 ppm	5.0 ppm	1.0 ppm	0.2 ppm
Instrument B	0.1 ppm	3.0 ppm	?	1.0 ppm	?
Instrument C	0.1 ppm	5.0 ppm	6.0 ppm	1.0 ppm	0.4 ppm

- When you have more than one type of instrument in service:
  - Make sure alarms match
  - Make sure datalogger settings match
  - Make sure you understand differences in the way the instruments record information and calculate alarms

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Conclusions

- Define the objectives behind the use of your real time instruments
  - Instrument capabilities need to match requirements
  - Instrument settings need to match objectives
  - Make sure you have sufficient resolution and accuracy
  - Make sure you understand interfering analytes and the effects of ambient conditions on readings
- Datalogging record needs to support objectives
  - Study the manual!
  - Download results and determine whether you understand how the instrument records information, and calculates alarms
- Make sure users are trained
  - Fresh air adjust before each day's use
  - Test and calibrate according to statutory and manufacturer requirements
  - Surveil to make sure settings are correct and that users follow proper procedures
  - Document!

Thank You!

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