OSHA® Occupational Safety and Health Administration

OSHA Method 1028, Hydrogen Sulfide

Hydrogen Sulfide

CAS number:	7783-06-4
OSHA PEL:	10 ppm (15 mg/m^3) 8-Hour TWA, Construction, Shipyard
	20 ppm (30 mg/m^3) Z-2 Ceiling, (10 minutes once, up to Z-2 Peak value, only if no other measurable exposure occurs), General Industry
	50 ppm (75 mg/m^3) Z-2 Peak, General Industry
IDLH:	100 ppm (150 mg/m^3)
Procedure:	Expose a personal gas monitor using a hydrogen sulfide (H$_2$S) electrochemical sensor to workplace air.
Recommended sampling time:	Full shift (up to approximately 8 hours with new batteries)
Reporting limit:	0.5 ppm
Working range:	0.5-200 ppm
Uncertainty (u):	18% (8-Hour TWA)
	8.3% (Z-2 Ceiling; apply when >20 ppm and ≤50 ppm)
	8.1% (Z-2 Peak; apply when >50 ppm)
	8.8% (IDLH)
Special requirements:	Do not use this method when dimethyl disulfide, dimethyl sulfide, and any mercaptans are present.
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1   Introduction

This method describes alternative methodologies to OSHA's use of OSHA Method 1008.[1] That method requires the collection of H_2S using silver nitrate-coated silica gel samplers combined with sodium carbonate/glycerol-treated glass fiber filters. This method uses a direct-reading monitor with an electrochemical sensor for on-site monitoring of hydrogen sulfide.

2   Monitoring Procedure

Follow all safety practices that apply to the work area where monitoring occurs.

2.1   Apparatus

- A multiple-gas personal gas monitor with a one-second or less datalogging interval, a ten-hour operating time (i.e., Dräger X-am 5600 Multi-Gas Detector with a firmware version of 7.8 or equivalent), synchronized to the OSHA Technical Center's time zone, and safety alarms set to the maximum value
- H_2S electrochemical sensor with a manufacturer-listed working range of 0-200 ppm and an internal selective filter for minimizing interferences (i.e., Dräger XXS H_2S LC or equivalent)
- Calibration adapter with chemically compatible tubing
- Calibration gas cylinders of H_2S at 20 and 50 ppm with a manufacturer-listed accuracy of ≤ ±5%
- Compatible calibration gas regulators with a fixed gas flow of 0.5 L/min
- Data communication adapter and cable
- Battery packs with rechargeable or non-rechargeable batteries
- NIST traceable temperature and barometric pressure monitor (i.e., Extech SD700 or equivalent)
- Monitor-specific software (i.e., Dräger CC-Vision Basic)

2.2   Technique

2.2.1   Calibration

To avoid being exposed to H_2S, perform calibration in a well-ventilated area and keep the end of the outlet tubing away from the personal breathing zone as far as possible.

Equilibrate the monitor to the ambient temperature of the monitoring site for at least 15 minutes. Power on the monitor and wait for completion of warm-up. Zero-calibrate the monitor by directly exposing it to clean air. Next, place the monitor into a calibration adapter supplied with 20-ppm H_2S calibration gas and wait until the reading is stabilized before span calibration.

Immediately following the span calibration, verify the monitor calibration using a 50-ppm H_2S calibration gas as a continuous calibration verification (CCV). Re-calibrate the monitor if the stabilized reading is not within 50 ± 5ppm.

2.2.2   Monitoring

Position the monitor securely in the worker's breathing zone. Record the time, atmospheric pressure, and temperature at the start and end of monitoring on the Form OSHA-91A.

At the end of monitoring, re-verify the monitor calibration using a 50-ppm H_2S calibration gas.

Turn off the monitor and return the monitoring equipment to the OSHA Technical Center with the Form OSHA-91A.

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3   Data Processing Procedure

3.1   Data Examination

Examine the downloaded monitoring data and identify all possible events including powering on and off, time synchronization, calibration, CCVs, monitoring duration, abnormal monitor readings, etc. Identify any responses over the IDLH. Report the potential of sensor saturation if any reading is over the maximum indication value of 200 ppm.

3.2   Determination of TWA

Calculate the time-weighted average (TWA) air concentration (C_s) in terms of parts of analyte per million parts of air (ppm) at the monitoring site temperature and pressure by summating all data points and dividing by the number of data points collected over the monitoring period. For example, divide by 14,400 when monitoring with a data collection rate of one second for 240 minutes. Use 200 ppm for any response over the maximum indication value of 200 ppm.

3.3   Determination of Z-2 Ceiling, Z-2 Peak and IDLH

Identify the highest air concentration (C_s) value in terms of parts of analyte per million parts of air (ppm) at the monitoring site temperature and pressure.

3.4   Calculation

Calculate the air concentration (C) in terms of ppm at 760 mmHg and 25 °C using Equation 1, where C_s is the measured monitoring site air concentration (ppm), P is the monitoring site atmospheric pressure (mmHg), and T is the monitoring site temperature (°C).

$$C = C_s \times \frac{P}{760\ mmHg} \times \frac{298.15\ K}{T + 273.15\ K}$$

(1)

The OSHA Integrated Management Information System (IMIS) number for H$_2$S is 1480.

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4   Method Validation

The procedures used to develop the method validation data are described in OSHA Technical Center's Guideline 2 *Direct-Reading Methods*.[2] The target concentration (T_C) values for method evaluation were the OSHA 8-hour TWA permissible exposure limit (PEL), Z-2 ceiling and peak for hydrogen sulfide.

Dynamically generated controlled test atmospheres were created in a walk-in hood for all validation tests. House air was regulated using a flow-temperature-humidity control system. A measured flow of 5% or 450-ppm hydrogen sulfide was introduced near the entrance of the test atmosphere, where it was mixed into a measured flow of dilution air from the flow-temperature-humidity control system. The hydrogen sulfide and dilution air flowed into a mixing chamber, and then into a testing chamber. Monitors were placed into the testing chamber. Temperature and humidity measurements were obtained near the exit of the testing chamber.

4.1   Time of Response

The time needed for the response to reach 63% of the final steady-state measured value (t_{63}) was determined by sampling dynamically generated controlled test atmospheres containing hydrogen sulfide at 19.4 and 49.5 ppm. The relative humidity and temperature of the air sampled were 29% and 21 °C. The t_{63} value was determined from signal rise of three monitors quickly placed into the test atmosphere, and signal decay of three monitors quickly removed after signal stabilization. Tests were performed six times at each concentration for each monitor. Results were calculated as described in *Direct-Reading Methods*.[2] Results obtained are provided in Table 1. The t_{63} value was determined to be 4 seconds.

Table 1. Time of response for hydrogen sulfide (ppm values listed at 639 mmHg and 21 °C).

| monitor no.	19.4 ppm rise in sec (%CV)	19.4 ppm decay in sec (%CV)	49.5 ppm rise in sec (%CV)	49.5 ppm decay in sec (%CV)	mean t_{63} in sec
monitor 1	3.6 (8.85%)	3.8 (7.00%)	4.0 (7.44%)	4.1 (8.19%)	3.9
monitor 2	3.6 (9.91%)	3.5 (7.48%)	3.8 (8.28%)	3.5 (6.09%)	3.6
monitor 3	3.4 (11.7%)	3.5 (4.19%)	3.6 (11.6%)	3.7 (8.43%)	3.6

4.2   Limit of Detection and Reporting Limit

The limit of detection (LOD) was determined by sampling dynamically generated controlled test atmospheres where the relative humidity and temperature of the air sampled were 80% and 21 °C. The LOD is the concentration that produces a response greater than 3.3× the standard error of estimate ($S_{y/x}$) divided by the slope of the line produced from three monitors used at six evenly spaced levels across a concentration range of 0 to 25 times the monitor resolution. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The reporting limit (RL) is designated to be 0.5 ppm, the nearest reading above the LOD resulting in a recovery ≤ ±25%. Results obtained are provided in Table 2 and plotted in Figure 1.

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Table 2. LOD and RL data for hydrogen sulfide (ppm values listed at 649 mmHg and 21 °C).

concn (ppm)	monitor no.	response (ppm)
0.00	monitor 1	0
0.00	monitor 2	0
0.00	monitor 3	0
0.498	monitor 1	0.5
0.498	monitor 2	0.4
0.498	monitor 3	0.4
0.998	monitor 1	1.0
0.998	monitor 2	1.0
0.998	monitor 3	1.0
1.50	monitor 1	1.5
1.50	monitor 2	1.5
1.50	monitor 3	1.4
1.99	monitor 1	1.9
1.99	monitor 2	1.9
1.99	monitor 3	1.9
2.49	monitor 1	2.4
2.49	monitor 2	2.5
2.49	monitor 3	2.5
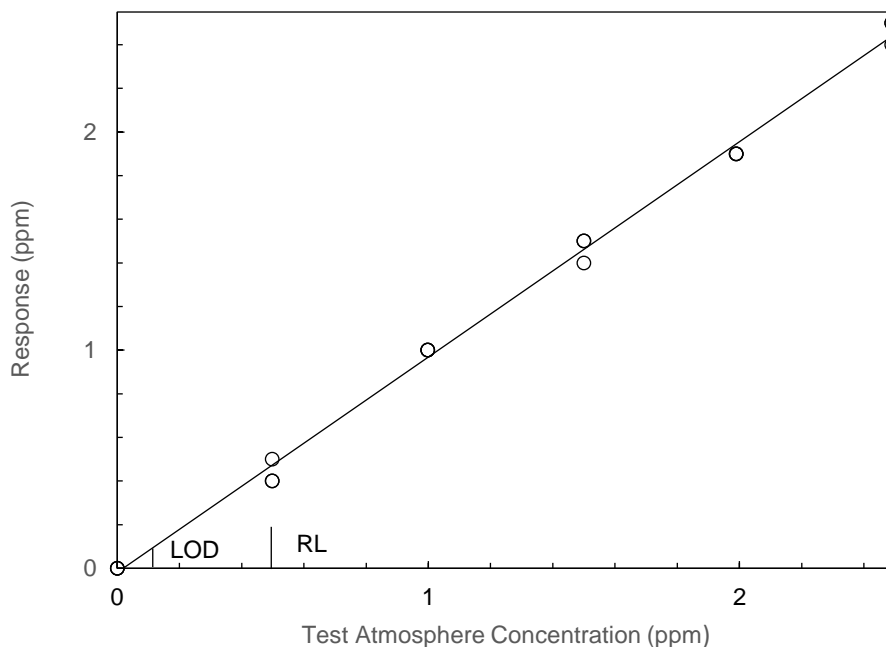
Figure 1. Plot of data used to determine the LOD and RL for hydrogen sulfide ($y = 0.987x - 0.0186$, $S_{y/x} = 0.0485$, LOD = 0.162 ppm, RL = 0.5 ppm).

4.3   Working Range

The working range was tested by sampling dynamically generated controlled test atmospheres where the relative humidity and temperature of the air sampled were 80% and 24 °C. Three monitors were used at ten evenly spaced

levels across a concentration range of the RL to 90% of the maximum indication value of 200 ppm. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). Results obtained are provided in Table 3.

Table 3. Working range data for hydrogen sulfide (ppm values listed at 651 mmHg and 24 °C).

concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.498	100.4	80.3	80.3	87.0
19.8	93.4	93.4	95.5	94.1
38.9	93.6	92.5	94.1	93.4
61.1	94.1	94.1	94.9	94.4
80.5	94.4	93.2	94.4	94.0
100	94.0	93.0	94.0	93.7
120	92.5	90.8	92.5	91.9
139	92.8	90.6	92.1	91.8
160	92.5	90.6	92.5	91.9
179	92.2	91.6	92.7	92.2

4.4 Method Precision and Bias

The 8-hour TWA method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 240 minutes. Three monitors were used at five levels across a concentration range of 0.1 to 5× the 8-hour TWA T_C. The results of these tests are provided in Table 4, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_TWA}) was 0.89%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_TWA}) was 1.3%. The resulting 8-hour TWA method precision (u_{mp_TWA}) for hydrogen sulfide was determined to be 1.4%. The mean recovery of all fifteen results was 95.8%, resulting in a method bias (B_{mp_TWA}) of 4.2% and a percent coefficient of variation (CV_{mb_TWA}) of 1.3%.

Table 4. Method precision data for hydrogen sulfide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.984	21	81	96.0	95.6	95.5	95.7
5.03	21	79	94.8	96.6	95.0	95.5
10.1	21	80	95.0	97.7	96.7	96.5
19.5	22	80	94.9	97.4	97.4	96.6
50.0	21	81	92.8	95.4	95.4	94.5

The Z-2 ceiling method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 10 minutes. Three monitors were used at five levels across a concentration range of 0.75 to 1.25× the Z-2 ceiling T_C. The results of these tests are provided in Table 5, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_CLG}) was 0.44%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_CLG}) was 1.4%. The resulting Z-2 ceiling method precision (u_{mp_CLG}) for hydrogen sulfide was determined to be 1.2%. The mean recovery of all fifteen results was 96.9%, resulting in a method bias (B_{mp_CLG}) of 3.1% and a percent coefficient of variation (CV_{mb_CLG}) of 1.3%.

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Table 5. Method precision data for hydrogen sulfide (Z-2 ceiling, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
15.1	21	80	96.0	98.7	98.0	97.6
18.1	21	80	95.0	97.8	97.2	96.7
19.9	21	80	95.5	98.0	97.5	97.0
22.0	21	80	95.0	97.7	97.3	96.7
25.1	21	80	95.2	97.6	96.8	96.5

The Z-2 peak method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 10 minutes. Three monitors were used at five levels across a concentration range of 0.75 to 1.25× the Z-2 peak T_C. The results of these tests are provided in Table 6, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_PEAK}) was 0.24%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_PEAK}) was 1.6%. The resulting Z-2 peak method precision (u_{mp_PEAK}) for hydrogen sulfide was determined to be 1.3%. The mean recovery of all fifteen results was 95.9%, resulting in a method bias (B_{mp_PEAK}) of 4.1% and a percent coefficient of variation (CV_{mb_PEAK}) of 1.4%.

Table 6. Method precision data for hydrogen sulfide (Z-2 peak, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
36.9	21	80	93.8	96.5	96.2	95.5
44.9	21	80	94.4	96.9	96.9	96.1
49.6	21	80	94.0	96.8	96.8	95.9
54.6	21	80	94.1	96.9	96.9	96.0
61.3	21	80	94.0	96.7	96.6	95.8

The IDLH method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 40 seconds (i.e., $t = 10 \times t_{63}$). Three monitors were used at five levels across a concentration range of 0.75 to 1.25× the IDLH T_C. The results of these tests are provided in Table 7, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_IDLH}) was 0.89%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_IDLH}) was 0.93%. The resulting IDLH method precision (u_{mp_IDLH}) for hydrogen sulfide was determined to be 1.2%. The mean recovery of all fifteen results was 92.5%, resulting in a method bias (B_{mp_IDLH}) of 7.5% and a percent coefficient of variation (CV_{mb_IDLH}) of 1.1%.

Table 7. Method precision data for hydrogen sulfide (IDLH, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
75.2	24	80	93.9	92.7	93.9	93.5
89.8	24	80	93.0	92.0	93.4	92.8
99.7	24	80	93.2	91.5	93.2	92.6
110	24	80	92.7	90.9	92.7	92.1
126	24	80	92.1	90.5	91.3	91.3

4.5 Effect of Face Velocity

The 8-hour TWA effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the 8-hour TWA T_C. The relative humidity and temperature of the air monitored

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were 80% and 22 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 8, along with the concentration of each test atmosphere. The effect of face velocity (Δ_{v_TWA}), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 3.1%.

Table 8. Face velocity data for hydrogen sulfide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	10.0	93.4	95.2	95.2	94.6
0.3	9.75	93.9	95.7	95.7	95.1
0.5	9.96	94.5	96.2	96.2	95.6
0.7	10.5	96.1	98.5	98.5	97.7
1.0	9.86	96.0	97.8	97.8	97.2

The Z-2 ceiling effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 ceiling T_C. The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 9, along with the concentration of each test atmosphere. The effect of face velocity (Δ_{v_CLG}), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 3.0%.

Table 9. Face velocity data for hydrogen sulfide (Z-2 ceiling, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	20.4	94.2	95.9	95.9	95.3
0.3	20.3	94.5	97.0	97.0	96.2
0.5	19.9	97.2	98.9	98.9	98.3
0.7	19.9	94.5	97.1	97.1	96.2
1.0	20.0	93.8	96.4	96.4	95.5

The Z-2 peak effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 peak T_C. The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 10, along with the concentration of each test atmosphere. The effect of face velocity (Δ_{v_PEAK}), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 1.4%.

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Table 10. Face velocity data for hydrogen sulfide (Z-2 peak, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	50.2	93.9	95.7	96.5	95.4
0.3	49.8	94.6	97.2	97.2	96.3
0.5	50.0	93.2	95.8	95.8	94.9
0.7	50.4	94.1	96.7	96.7	95.8
1.0	49.8	94.2	96.8	96.8	95.9

The IDLH effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the IDLH T_C. The relative humidity and temperature of the air monitored were 80% and 24 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 11, along with the concentration of each test atmosphere. The effect of face velocity (Δ_{v_IDLH}), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 2.2%.

Table 11. Face velocity data for hydrogen sulfide (IDLH, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	99.0	93.7	93.7	93.7	93.7
0.3	99.0	93.9	93.9	93.9	93.9
0.5	99.7	95.8	95.0	95.8	95.5
0.7	99.7	95.5	95.5	95.5	95.5
1.0	100	95.9	95.9	95.9	95.9

4.6 Effect of Orientation

The 8-hour TWA effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the 8-hour TWA T_C. The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice. The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 12, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_TWA}), calculated as the absolute difference between the two orientations tested was 2.2%.

Table 12. Orientation data for hydrogen sulfide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	9.96	94.5	96.2	96.2	95.6
90	9.86	96.0	99.5	97.8	97.8

The Z-2 ceiling effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 ceiling T_C. The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice. The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 13, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_CLG}), calculated as the absolute difference between the two orientations tested was 1.9%.

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Table 13. Orientation data for hydrogen sulfide (Z-2 ceiling, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	19.9	97.2	98.9	98.9	98.3
90	20.0	94.7	97.3	97.3	96.4

The Z-2 peak effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 peak T_C. The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice. The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 14, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_PEAK}), calculated as the absolute difference between the two orientations tested was 2.2%.

Table 14. Orientation data for hydrogen sulfide (Z-2 peak, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	50.0	93.2	95.8	95.8	94.9
90	49.8	95.1	98.5	97.7	97.1

The IDLH effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the IDLH T_C. The relative humidity and temperature of the air monitored were 80% and 24 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice. The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 15, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_IDLH}), calculated as the absolute difference between the two orientations tested was 0.60%.

Table 15. Orientation data for hydrogen sulfide (IDLH, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	99.7	95.9	95.0	95.9	95.6
90	100	95.0	95.0	95.0	95.0

4.7 Effect of Humidity

The 8-hour TWA effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the 8-hour TWA T_C for 240 min (calculated to be 10.1 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 20% and 21 °C. Results for hydrogen sulfide as a percentage of expected recovery of the three monitors was 93.6%, 95.5%, and 95.8%. The mean percentage of expected recovery was 95.0%. The effect of humidity (Δ_{h_TWA}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 96.5% taken from the 10.1 ppm method precision test described in Section 4.4, was 1.5%.

The Z-2 ceiling effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 ceiling T_C for 10 min (calculated to be 20.6 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 20% and 21 °C. Results for hydrogen sulfide as a percentage of expected recovery of the three monitors was 91.7%, 94.2%, and 92.7%. The mean percentage of expected recovery was 92.9%. The effect of humidity (Δ_{h_CLG}), calculated as the absolute difference between the mean

dry recovery and the mean humid recovery of 97.0% taken from the 19.9 ppm method precision test described in Section 4.4, was 4.1%.

The Z-2 peak effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 peak T_C for 10 min (calculated to be 49.8 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 20% and 21 °C. Results for hydrogen sulfide as a percentage of expected recovery of the three monitors was 92.4%, 94.6%, and 93.4%. The mean percentage of expected recovery was 93.4%. The effect of humidity (Δ_{h_PEAK}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 95.9% taken from the 49.6 ppm method precision test described in Section 4.4, was 2.5%.

The IDLH effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the IDLH T_C for 40 seconds (i.e., $t = 10 \times t_{63}$) (calculated to be 99.6 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 20% and 21 °C. Results for hydrogen sulfide as a percentage of expected recovery of the three monitors was 93.4%, 92.5%, and 92.5%. The mean percentage of expected recovery was 92.8%. The effect of humidity (Δ_{h_IDLH}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 92.6% taken from the 100 ppm method precision test described in Section 4.4, was 0.2%.

4.8   Effect of Interferents

Any substances that interact with the working electrode of the H_2S electrochemical sensor can potentially interfere with measurements during H_2S monitoring. Due to high cross-sensitivities of the sensor to dimethyl disulfide, dimethyl sulfide, and mercaptans, it is necessary to confirm the presence of these substances in the contaminated air if suspected.

4.9   Effect of Intermittent Exposure

The 8-hour TWA effect of intermittent exposure was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the 8-hour TWA T_C (calculated to be 9.95 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 32% and 22 °C. All monitors were exposed to the test atmosphere for 9 seconds (i.e., $t = 2.3 \times t_{63}$) followed by 9 seconds of clean air recovery, where the exposure cycle was repeated ten times for a 90-second intermittent exposure. Subsequently, the monitors were exposed to the test atmosphere for a 90-second steady exposure. Results as a percentage of expected recovery of the three monitors are provided in Table 16. The effect of intermittent exposure (Δ_{ie_TWA}), calculated as the absolute difference between the mean intermittent exposure recovery and the mean steady exposure recovery, was 27%.

Table 16. Intermittent exposure data for hydrogen sulfide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

total exposure time (s)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
90 (intermittent)	123.9	125.8	126.9	125.5
90 (steady)	96.6	99.7	100.1	98.8

The Z-2 ceiling effect of intermittent exposure was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 ceiling T_C (calculated to be 20.0 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 32% and 22 °C. All monitors were exposed to the test atmosphere for 9 seconds (i.e., $t = 2.3 \times t_{63}$) followed by 9 seconds of clean air recovery, where the exposure cycle was repeated ten times for a 90-second intermittent exposure. Subsequently, the monitors were exposed to the test atmosphere for a 90-second steady exposure. Results as a percentage of expected recovery of the three monitors are provided in Table 17. The effect of intermittent exposure (Δ_{ie_CLG}), calculated as the absolute difference between the mean intermittent exposure recovery and the mean steady exposure recovery, was 19%.

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Table 17. Intermittent exposure data for hydrogen sulfide (Z-2 ceiling, ppm values listed at 760 mmHg and 25 °C).

total exposure time (s)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
90 (intermittent)	115.0	116.6	118.2	116.6
90 (steady)	95.6	98.0	98.5	97.4

4.10 Effect of Temperature

The 8-hour TWA effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the 8-hour TWA T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 80% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 21 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 18, along with the concentration of each test atmosphere. The effect of temperature (Δ_{T_TWA}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 2.4%.

Table 18. Temperature data for hydrogen sulfide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	10.0	93.6	95.3	94.5	94.5
21	10.1	93.5	95.2	94.3	94.3
50	10.0	90.0	94.4	91.8	92.1

The Z-2 ceiling effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 ceiling T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 80% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 21 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 19, along with the concentration of each test atmosphere. The effect of temperature (Δ_{T_CLG}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 2.9%.

Table 19. Temperature data for hydrogen sulfide (Z-2 ceiling, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	19.8	94.6	97.2	95.4	95.7
21	20.0	94.4	97.0	96.1	95.8
50	20.0	90.9	95.2	92.6	92.9

The Z-2 peak effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the Z-2 peak T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 80% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 21 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 20, along with the concentration of each test atmosphere. The effect of temperature (Δ_{T_PEAK}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 3.0%.

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Table 20. Temperature data for hydrogen sulfide (Z-2 peak, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	49.6	94.4	97.0	96.1	95.8
21	50.0	94.4	97.0	96.1	95.8
50	49.9	90.2	95.4	92.8	92.8

The IDLH effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at the IDLH T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 80% and 24 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 24 °C, and 50 °C for one hour, respectively. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The reconstructed results of these tests are provided in Table 21, along with the concentration of each test atmosphere. The effect of temperature (Δ_{T_IDLH}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 3.4%.

Table 21. Temperature data for hydrogen sulfide (IDLH, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	99.7	94.1	93.2	95.0	94.1
24	99.6	93.9	93.9	93.9	93.9
50	99.9	90.2	91.0	91.0	90.7

4.11   Effect of Oversaturation

The effect of oversaturation was tested by monitoring a dynamically generated controlled test atmosphere containing hydrogen sulfide nominally at 2× the maximum indication value of 200 ppm for 10 minutes (calculated to be 402 ppm at 650 mmHg and 22 °C). The relative humidity and temperature of the air sampled were 81% and 22 °C. After oversaturation for 10 minutes, followed by recovery with clean air for 60 minutes, the monitor response drift between pre and post CCVs described in Section 2.2 was observed to be -5.6%.

4.12   Reproducibility

A dynamically controlled test atmosphere was generated, containing hydrogen sulfide nominally at the 8-hour TWA T_C (calculated to be 10.2 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 81% and 22 °C. The test atmosphere was monitored by Production Team for 240 min using the monitoring procedure described in Section 2 of this method. The monitor results were then submitted to the OSHA Technical Center for analysis using the data processing procedure described in Section 3 of this method. The monitoring results are provided in Table 22. No sample result for hydrogen sulfide fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

Table 22. Reproducibility data for hydrogen sulfide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

monitored (ppm)	recovery (%)	deviation (%)
9.73	95.4	- 4.6
9.98	97.8	- 2.2
9.91	97.2	- 2.8

A dynamically controlled test atmosphere was generated, containing hydrogen sulfide nominally at the Z-2 ceiling T_C (calculated to be 20.0 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 80% and 22 °C. The test atmosphere was monitored by Production Team for 10 minutes using the monitoring procedure described in Section 2 of this method. The monitor results were then submitted to the OSHA Technical Center for

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analysis using the data processing procedure described in Section 3 of this method. The monitoring results are provided in Table 23. No sample result for hydrogen sulfide fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

Table 23. Reproducibility data for hydrogen sulfide (Z-2 ceiling, ppm values listed at 760 mmHg and 25 °C).

monitored (ppm)	recovery (%)	deviation (%)
18.6	93.0	- 7.0
19.1	95.5	- 4.5
19.0	95.0	- 5.0

A dynamically controlled test atmosphere was generated, containing hydrogen sulfide nominally at the Z-2 peak T_C (calculated to be 50.2 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 80% and 22 °C. The test atmosphere was monitored by Production Team for 10 minutes using the monitoring procedure described in Section 2 of this method. The monitor results were then submitted to the OSHA Technical Center for analysis using the data processing procedure described in Section 3 of this method. The monitoring results are provided in Table 24. No sample result for hydrogen sulfide fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

Table 24. Reproducibility data for hydrogen sulfide (Z-2 peak, ppm values listed at 760 mmHg and 25 °C).

monitored (ppm)	recovery (%)	deviation (%)
46.2	92.0	- 8.0
47.8	95.2	- 4.8
47.5	94.6	- 5.4

4.13 Estimation of Uncertainty

Hydrogen sulfide relative standard uncertainty components (u_i) are provided in Table 25 for both the 8-hour TWA, Z-2 ceiling, Z-2 peak and IDLH levels. The combined percent relative standard uncertainty of the monitoring procedure (u) was determined to be 18% for the 8-hour TWA, 8.3% for Z-2 ceiling, 8.1% for Z-2 peak and 8.8% for the IDLH. The expanded uncertainty (U) was determined to be 36% for the 8-hour TWA, 17% for Z-2 ceiling, 16% for Z-2 peak and 18% for the IDLH.

Table 25. Uncertainty.

uncertainty component (u_i)	8-hour TWA (%)	Z-2 Ceiling (%)	Z-2 Peak (%)	IDLH (%)	notes
calibration standards (u_{cs})	2.9	2.9	2.9	2.9	$u_{cs} = 5\%/\sqrt{3}$, assumes an accuracy of ±5%
method precision (u_{mp})	1.4	1.2	1.3	1.2	$u_{mp} = \sqrt{(CV_m)^2 + (1 - 1/n) \times (CV_{pl})^2}$, where $CV_{m\_TWA} = 0.89\%$, $CV_{pl\_TWA} = 1.3\%$, $CV_{m\_CLG} = 0.44\%$, $CV_{pl\_CLG} = 1.4\%$, $CV_{m\_PEAK} = 0.24\%$, $CV_{pl\_PEAK} = 1.6\%$, $CV_{m\_IDLH} = 0.89\%$, $CV_{pl\_IDLH} = 0.93\%$, and $n = 3$, see Section 4.4
method bias (u_{mb})	3.9	3.5	3.8	5.3	$u_{mb} = \sqrt{(B_{mb}/\sqrt{3})^2 + (CV_{mb}/\sqrt{n})^2 + (u_{rc})^2}$, where $B_{mb\_TWA} = 4.2\%$, $CV_{mb\_TWA} = 1.3\%$, $B_{mb\_CLG} = 3.1\%$, $CV_{mb\_CLG} = 1.3\%$, $B_{mb\_PEAK} =$

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uncertainty component (u_i)	8-hour TWA (%)	Z-2 Ceiling (%)	Z-2 Peak (%)	IDLH (%)	notes
					4.1%, CV_{mb_PEAK} = 1.4%, B_{mb_IDLH} = 7.5%, CV_{mb_IDLH} = 1.1%, and n = 15, see Section 4.4; u_{rc} = 3%, see Reference 3
effect of face velocity (u_v)	1.8	1.7	0.81	1.3	$u_v = \Delta_v/\sqrt{3}$, where Δ_{v_TWA} = 3.1%, Δ_{v_CLG} = 3.0%, Δ_{v_PEAK} = 1.4%, and Δ_{v_IDLH} = 2.2%, see Section 4.5
effect of orientation (u_o)	1.3	1.1	1.3	0.35	$u_o = \Delta_o/\sqrt{3}$, where Δ_{o_TWA} = 2.2%, Δ_{o_CLG} = 1.9%, Δ_{o_PEAK} = 2.2%, and Δ_{o_IDLH} = 0.60%, see Section 4.6
effect of humidity (u_h)	0.87	2.4	1.4	0.12	$u_h = \Delta_h/\sqrt{3}$, where Δ_{h_TWA} = 1.5%, Δ_{h_CLG} = 4.1%, Δ_{h_PEAK} = 2.5%, and Δ_{h_IDLH} = 0.2%, see Section 4.7
effect of intermittent exposure (u_{ie})	16	N/A	N/A	N/A	$u_{ie} = \Delta_{ie}/\sqrt{3}$, where Δ_{ie_TWA} = 27%, and Δ_{ie_CLG} = 19%, see Section 4.9
effect of temperature (u_T)	1.4	1.7	1.7	2.0	$u_T = \Delta_T/\sqrt{3}$, where Δ_{T_TWA} = 2.4%, Δ_{T_CLG} = 2.9%, Δ_{T_PEAK} = 3.0%, and Δ_{T_IDLH} = 3.4%, see Section 4.10
resolution (u_r)	0.29	0.29	0.29	0.29	$u_r = [Res/(2 \times \sqrt{3} \times T_C)] \times 100\%$, where Res_{TWA} = 0.1 ppm, T_{C_TWA} = 10 ppm, Res_{CLG} = 0.2 ppm, T_{C_CLG} = 20 ppm, Res_{PEAK} = 0.5 ppm, T_{C_TWA} = 50 ppm, and Res_{IDLH} = 1 ppm, T_{C_IDLH} = 100 ppm
monitor response drift (u_{dr})	5.8	5.8	5.8	5.8	$u_{dr} = 10\%/\sqrt{3}$, assumes a maximum monitor response drift of ±10%
temperature measurement (u_{AT})	0.16	0.16	0.16	0.16	$u_{AT} = 0.27\%/\sqrt{3}$, assumes a measured accuracy of ±0.8 °C at 25 °C
pressure measurement (u_{bp})	0.12	0.12	0.12	0.12	$u_{bp} = 0.20\%/\sqrt{3}$, assumes a measured accuracy of ±1.5 mmHg at 760 mmHg
standard uncertainty (u)	18	8.3	8.1	8.8	$u = \sqrt{\Sigma(u_i^2)}$, where u_i represents each uncertainty component as shown above
expanded uncertainty (U)	36	17	16	18	$U = k \times u$, where k = 2

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