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An Evaluation of H_2S Continuous Monitors Using Metal Oxide Semiconductor Sensors

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Five brands of commercially available hydrogen sulfide (H_2S) monitors employing metal oxide semiconductor sensors were evaluated to determine their suitability for continuous monitoring applications and concentration measurement. Three brands of the monitors employ a two point calibration and linearization in an attempt to obtain concentration data from the sensors. The two remaining brands employ a one point calibration. Information concerning the performance of the monitors is reported, including long-term zero and span stability, response time, and response with various temperatures, humidities, and interferences. All monitors had very good long-term zero stability under all conditions. The long-term span stability of the monitors employing a two point calibration technique and linearization of the sensor signal was, in general, better than those employing a one point calibration technique. None of the monitors was affected greatly by the interferences examined (CO and CH_4). All of the monitors were affected to some degree by temperature and humidity, but there were significant differences in the kind and level of the effects. Humidity at −7°C (20°F) to 49°C (120°F) had little effect on one brand of monitor but greatly increased the response of the two other brands of monitors. The remaining two brands showed some effect due to humidity, but the effect was not consistent.

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Introduction

Monitors that can provide a warning in the presence of hazardous concentrations of chemical substances are valuable in the prevention of worker exposure. A number of these monitors are commercially available. Some of the simpler and least expensive are based upon the use of electrochemical and solid-state semiconductor sensors.(1) Because monitors using semiconductor sensors have been on the market for some time and there has been continuous development of monitors based on these sensors, a study was conducted to assess their operating characteristics and to determine their effectiveness in continuous monitoring applications.

Continuous monitoring applications have two possible purposes. First, the monitors may be used for warning purposes. Workers are informed only if concentrations are above a certain alarm level; data are not recorded. Secondly, data may be recorded to develop information concerning the actual concentration and how it varies with time. These data can be used to assess exposures, evaluate controls, or identify problem areas in the workplace.

The semiconductor sensors are simple and rugged and can operate in the work environment without any special controls such as those for temperature and humidity.(1) This allows continuous monitoring with minimum expense due to purchase cost, installation, or operation and maintenance. One of the primary uses for monitors employing semiconductor sensors is the monitoring of hydrogen sulfide (H_2S). H_2S is encountered in a number of operations, especially in petroleum production where the operation of complex instrumentation is not practical.

Because of its smell, H_2S is easily detected; however, olfactory fatigue can occur fairly rapidly at higher concentrations. Low concentrations can cause respiratory irritation while high concentrations can cause rapid respiratory arrest. There are several exposure standards and recommended guidelines for H_2S. The National Institute for Occupational Safety and Health recommended exposure level(2) is a 10 ppm ceiling for a 10-minute sampling period; the Occupational Safety and Health Administration standard is a 20 ppm ceiling with a 50 ppm 10-minute peak;(3) and the American Conference of Governmental Industrial Hygienists Threshold Limit Value(4) is a 10 ppm time-weighted average (TWA) with a 15 ppm short-term exposure limit (STEL). The Immediately Dangerous to Life and Health (IDLH) limit is 300 ppm.(5) The instruments used for monitoring should be able to detect concentrations corresponding to these various criteria. If an instrument is to be used only for warning purposes, accuracy requirements would not be as stringent as those for an instrument that is to be used for concentration measurement.

The accuracy required depends on the application and how the data are to be used. To measure worker exposure, methods are generally required to give an accuracy of ± 25 percent for

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Mention of company names does not constitute endorsement by the National Institute for Occupational Safety and Health.

95 percent of the measurements.(6) This accuracy is for samples collected in the field and analyzed in a laboratory. It is somewhat difficult to apply these criteria to continuous monitors since factors, such as frequency of calibration, can affect the accuracy. The frequency of calibration should be adjusted such that the accuracy requirements are met. Monitors used for warning might be required to give an accuracy of ± 50 percent although no criteria have been established for this type of monitor.

Monitors employing semiconductor sensors have been evaluated in the past.(7, 8) In the first such study, these types of sensors were relatively new and had poor linearity and some interference problems. In the second study, the sensors available had improved and demonstrated good linearity and selectivity. However, they were not evaluated for their use as continuous monitors.

Experimental

Monitors Examined

There are a number of H_2S monitors that employ metal oxide solid-state sensors. Monitors used in this study (Table I) were chosen from those manufacturers that were found to have the largest number in use and were meant to represent a cross-section of those available. No endorsement of any of the monitors examined is intended over those made by other manufacturers. Development is continuing in this field, and newer sensors and methods of handling the signals from the sensors are likely to be marketed in the future.(9)

All of the monitors examined consisted of a remote sensor wired to a controller. The sensor, which is very small, consists of a metal oxide film, coated on a heated ceramic substrate and typically enclosed in a porous housing that serves as a flame arrestor and shield. This shield extends from a rugged conduit box made to prevent exposure to explosive atmospheres. The gas to be measured must diffuse through the shield to arrive at the sensor. In certain applications, this shield might be covered by other shields and splash guards. The conduit box also contains electronics that are needed to control the sensors and to send signals from the sensors to the controller. The sensors can be located at distances up to a mile from the controller on some models. The controller contains the readout and alarm electronics and supplies power to the remote sensors.

The monitors studied can be divided into two types, based on how the signal from the sensor is handled by the controller electronics and on how the monitors are calibrated. The General Monitors, Rexnord, and MSA monitors electronically linearize the output from the sensors. The Bacharach and Texas Analytical Controls monitors use nonlinear scales on the controllers since they do not linearize the signal from the sensors electronically. The monitors with linearized output require calibration at two different concentrations while those with nonlinear scales were calibrated at only one concentration.

TABLE I. Monitors Studied

Two General Monitors Model 2180—designated G1 and G3—electronic linearization at microprocessor controller
Two Rexnord Model 710—designated R4 and R9—electronic linearization of digital readout at controller
Two MSA Model 500—designated M2 and M10—electronic linearization of signal at sensor
Two Texas Analytical Controls Model 110—designated T5 and T6—nonlinear scale on controller
One Bacharach Model 550 controller—with two sensors designated B7 and B8—nonlinear scale on controller

H_2S Generation System

Various concentrations of H_2S were generated by diluting a standard H_2S mixture (1000 ppm in N_2) with air. The flows of air, H_2S mixture, and interferences were controlled with flow controllers designed to provide a constant flow in spite of changes in outlet pressure. To control the air and interferences gas lines, Vici-Condyne model 100 flow controllers were used. For the H_2S mixture, Vici-Condyne model SS-202 flow controllers were used. There were two separate air streams, one of which passed through a humidifier so that different mixtures of wet and dry air were obtained. The water in the humidifier also could be heated to obtain higher humidities. After the wet and dry air were mixed, the mixture entered a temperature controlled chamber. Temperatures between −7° to 71°C (20° to 160°F) were obtained in this chamber. Upon entering this chamber, the airflow passed through a temperature equilibration coil, and the H_2S mixture was added. The final mixture passed through a smaller diameter piece of tubing that acted as a mixer. Two different flow controllers were used with the H_2S standard mixture, one providing a high flow for high concentrations (10–110 ppm) and one providing a low flow for lower concentrations (2–15 ppm). The low flow could also be used to provide a low concentration background to which a larger flow for a larger concentration could be added. The interferences were mixed with the airflow before entering the temperature controlled chamber. The interferents were 1000 ppm carbon monoxide (CO) and 1000 ppm methane (CH_4) in air which were obtained by dilution of higher concentration mixtures. The sensors were enclosed in small Teflon® exposure caps that were plumbed in series to expose all sensors at approximately the same time. Since the volume of the caps compared to the flow rate was small, the concentration to which the sensors were exposed could be changed quickly. Experiments showed that the concentration reached its final value within five seconds of the time that the flow settings were changed.

The concentration of H_2S being generated by the system was measured by a gas chromatographic technique using flame photometric detection.(10) The gas chromatograph was calibrated with mixtures prepared in aluminized polyester bags by injecting known volumes of 98 percent H_2S from a lecture bottle into calibrated volumes of air.

Test Characteristics

A number of characteristics are of interest with this type of monitor, including zero and span stability, linearity of response, response time, and the effects of variables such as temperature, humidity, and other gaseous interferences on the monitor response. The effects of these variables were examined under conditions representing extreme conditions that might be encountered in field applications. Zero and span stability for long-term operation were evaluated since these monitors would be operated for extended periods in the workplace with minimum maintenance and calibration. It was decided that this information could best be obtained by spanning the monitors on an infrequent basis while keeping track of their response at various concentrations as a function of time.

Three sets of experiments were conducted to determine the effects on response of temperature, humidity, and interferences, either singly or in combination.

The first two experiments were done in a factorial design. The first experiment was done at room temperature (23°C) and 40 percent relative humidity (RH) and examined the effect of CH_4 and CO on the response of the monitors over a range of concentrations. The concentrations of CO and CH_4 used were nominally 1000 ppm; there was not an affect on the zero air response of any of the monitors. At each H_2S concentration (from 0–70 ppm), a four-test factorial experiment (constituting a block) was conducted. The four conditions studied were 1) both CO and CH_4 present, 2) only CH_4 present, 3) only CO present, and 4) CO and CH_4 absent. At each concentration, the tests were conducted in the above order.

The second factorial design experiment was used to determine the combined effects of temperature, humidity, CO, and CH_4 on the response of the monitors. A factorial design suggests measuring the parameter of interest (i.e., the response curve) at extremes in the values of the variables. In this case, the effects of temperature at extremes in humidity would be measured, but this is not possible since humidity depends upon temperature. It was not possible to control or measure the humidity at the lower temperature (which was −7°C [20°F]; even at 100 percent RH air would be dry at this temperature), and therefore, only one humidity was used. A high humidity (e.g., 80 percent RH) at the higher temperature (which was 69°C [157°F]) would represent a very large amount of water in the air. Forty percent RH was used as the higher humidity at the higher temperature, and this represents a partial pressure of water of about 80 mm of Hg, which is about four times saturation at room temperature. The factorial experiment chosen was intended to be a half-fraction of a full factorial. The fraction chosen confounds (mixes up) any interaction of methane and temperature-humidity level with the methane and temperature-humidity level main effects. However, by comparison with the results of other experiments, useful information can be obtained from this experiment.

For each experimental run, the response of the monitors to various concentrations of H_2S from 0–50 ppm was first determined under a set of reference conditions (40% RH and 24°C [75°F]) and then under test conditions. This was done so that the response under the test conditions of differing humidity, temperature, CO, and CH_4 could be compared to the response at the reference conditions. Thus any changes in the calibration of the monitors with time would not affect the analysis of the data. For each monitor, a response function was fitted to its response versus concentration at the reference and test conditions. These response functions were used to calculate the predicted response of the monitors at several concentrations at the reference and test conditions. For each monitor, the difference between the predicted value at the experimental condition and that at the reference condition was determined at 5, 15, 25, 35, and 45 ppm. For each monitor at each concentration level, an analysis of variance was carried out on the eight differences at that concentration level.

To further investigate the effects of temperature and humidity, a set of experiments at 24°C (74°F) and a set at 49°C (121°F) were performed. In these experiments, the temperature was held constant, but the humidity was varied over a large range.

Results and Discussion

Zero Stability

The output of the monitors with zero air was measured about three times a week over a six-month period. None of the monitors showed any measurable zero drift during the study period, even when exposed to varying temperature and humidity. Zero drift was not found to be a problem.

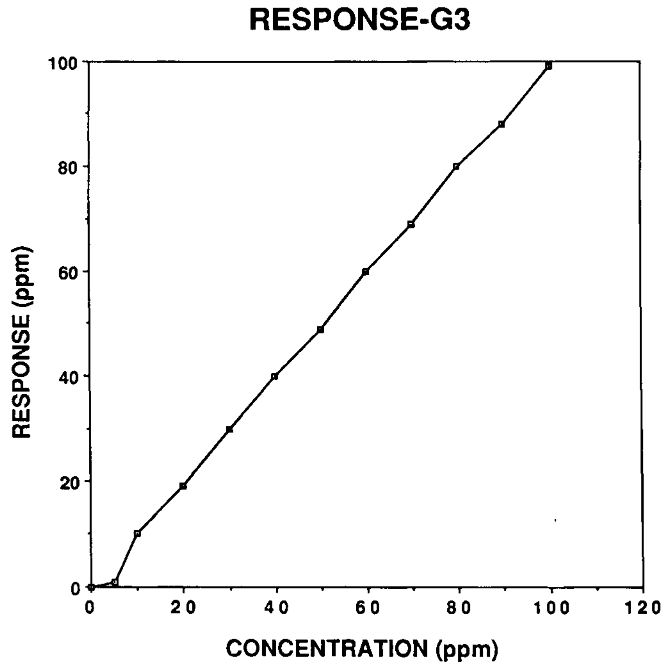

FIGURE 1. Response vs. concentration for monitor G3.

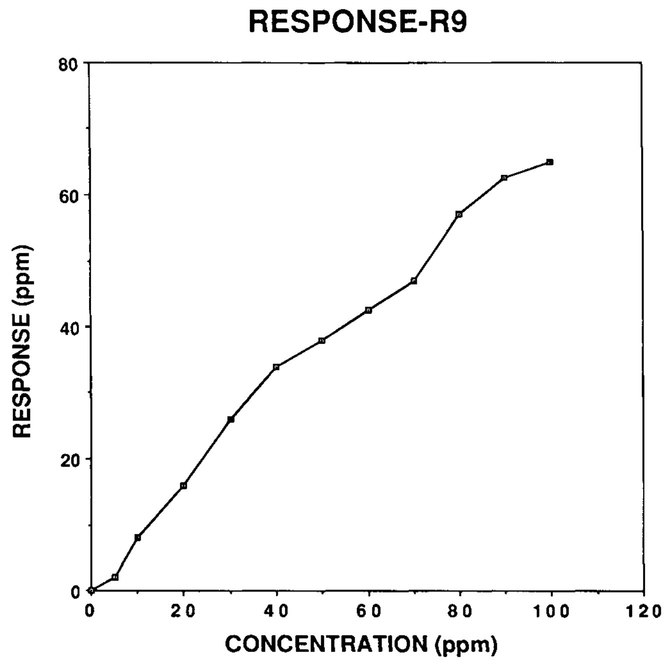

FIGURE 2. Response vs. concentration for monitor R9.

Linearity and Stability of Response

To determine the linearity and the stability of response, the response curve was determined for a number of dates over an extended period of time. This was done at constant humidity and temperature (40% RH and 23°C [74°F]).

Figures 1–5 show the response vs. concentration for one of each brand of monitor over a period of 2.5 months. The response curves of the monitors were determined on a number of dates during the 2.5 months, and the average response vs. concentration is given in the figures. Monitors of the same brand showed similar, although not identical, response curves. For each brand

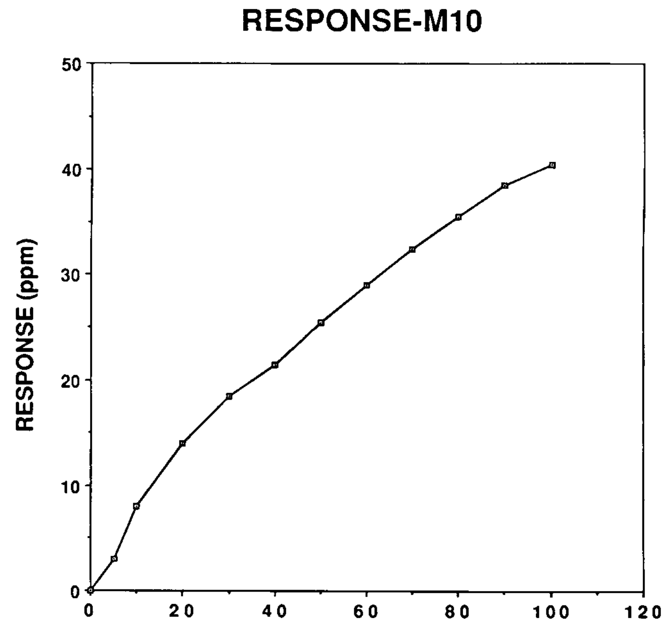

FIGURE 3. Response vs. concentration for monitor M10.

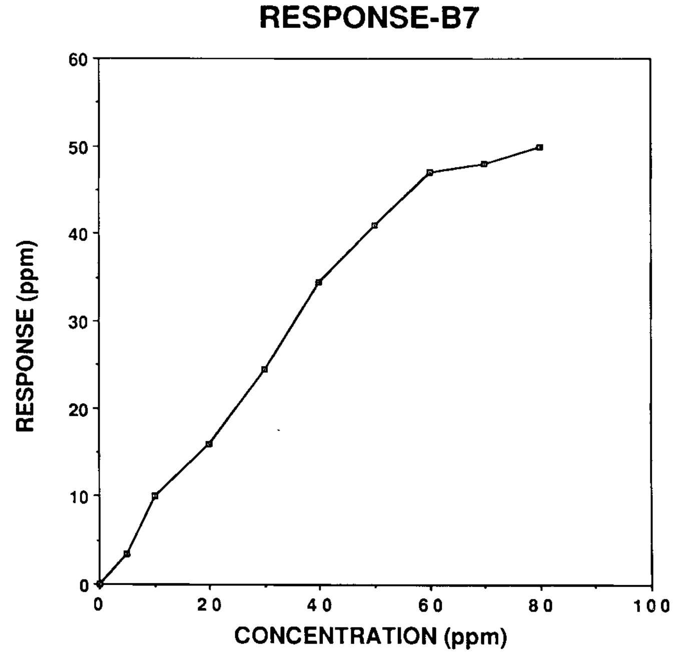

FIGURE 4. Response vs. concentration for monitor B7.

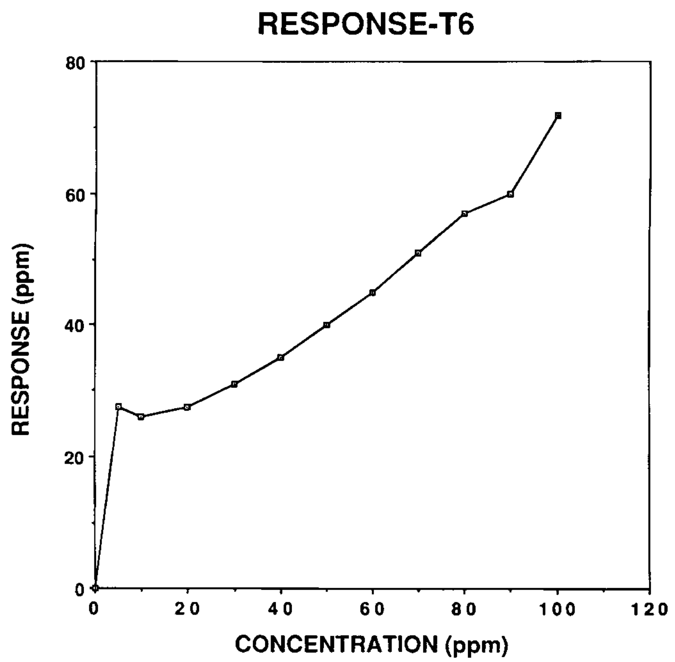

FIGURE 5. Response vs. concentration for monitor T6.

of monitor (except T5 and T6), a response function was fitted for each response curve determined on different dates.

The response of the G1 and G3 monitors was approximated by a straight line with some quadratic contribution in the range of 0–100 ppm. The G1 and G3 monitors did not respond quantitatively to concentrations below about 5 ppm.

Two piece curves could be used to describe the response of the R4 and R9 monitors for each day on which the response curve was determined—one curve to about 40 ppm, the upper calibration point, and another curve from 40 to 100 ppm. R4 and R9 did not respond quantitatively to concentrations below about 5 ppm.

The other monitors showed more complex curves. In general B7, B8, T6, T5, M2, and M10 responded to levels below 5 ppm. The M2 and M10 monitors had a quadratic response (a response curve involving a linear and quadratic term) up to about 20 ppm (the upper calibration point) when properly calibrated, but they had a different quadratic response above 20 ppm. The scales on these monitors read from 0–50 ppm, but the monitors read less than 50 ppm even if the concentration reached 100 ppm. The B7 and B8 monitors needed a recalibrated scale. The response was off scale at about 50 ppm, in spite of the fact that the scale on the controller went up to 100 ppm. Recently calibrated, B7 and B8 displayed linear response up to 50 ppm on the recalibrated scale, but when they were out of calibration, more complicated behavior was observed. The T5 and T6 monitors read up to 100 ppm, but the output was a complicated function of concentration.

To examine the stability of response as a function of time, the response of the monitors was determined on a number of days over a period of time. The monitors were calibrated three times during the 2.5-month period during which these response curves were determined.

For monitors exhibiting linear behavior, the results are easier to interpret. For G3 and R9, these differences were approximated by straight lines. This makes the relative maximum difference in response, dR/C (where dR is the estimated maximum difference in response and C is the concentration), a constant value regardless of concentration for these monitors. Table II shows estimates of the maximum change in response for the monitors studied. For G3, the relative maximum difference in response is about 20 percent of concentration while the maximum relative

TABLE II. Maximum Relative Change in Response with Time

Monitor	% Difference*	Monitor	% Difference*
G3, G1	20	M2, M10	100
B7, B8	100	R4, R9	50
T6, T5	100		

*Maximum relative difference between the largest and smallest response curves during the 2.5 months of the study.

difference in response for R9 is about 50 percent of the concentration. For B7 and M10, the maximum relative difference in response is not linear as a function of concentration over the range (0–50 ppm). For M10, the maximum relative difference in response varies from over 100 percent at 10 ppm to about 30 percent at 50 ppm. For B7, the maximum relative difference varies from 100 percent at 10 ppm to about 50 percent at 50 ppm.

Response Time

The response time of the different brands of monitor varied considerably. There were a number of factors determining response time, including the concentration to which the monitor was exposed and how recently the monitor had been exposed to any concentration of H_2S. Table III shows the 75 percent response time (the time to reach 75% of final response) of each brand of monitor averaged over all concentrations. R4 and R9 had very short response times while several of the monitors had much longer response times. In general, the response times were shorter at higher concentrations.

TABLE III. Response time

Monitor	Response Time (sec)*	Fall Time (sec)*
G3, G1	150	21
B7, B8	19	17
T6, T5	152	200
M2, M10	123	167
R4, R9	10	15

*Time to reach 75% of final response averaged over all concentrations.

Fall times were also studied by exposing the monitors to 100 ppm H_2S for a period of time and then rapidly changing the exposure to clean air. The presence of a low background concentration decreased the response time for several monitors, especially the G1 and G3 monitors, G1 and G3 monitors were able to track changes in concentration fairly rapidly once they had begun to respond. This means that they would be able to show changes in concentration even if these changes were rapid, but they would respond slowly to an initial increase in concentration if they were being exposed to clean air.

Effects of Temperature, Humidity, and Interferences

In the first factorial design experiment, which measured the effects of CO and CH_4 at constant temperature and humidity, only four monitors showed a statistically significant effect for CO and CH_4. Interactions between CO and CH_4 were never statistically significant at the 10 percent level. The results for these monitors are shown in Table IV. For both CO and CH_4, the difference is the response with CO and/or CH_4 present minus the response with CO and/or CH_4 absent divided by the response with CO and/or CH_4 absent. The values in the table are averages over the concentration range studied.

In the second factorial design experiment which measured the effects of humidity, temperature, and interferences in combination, there were a number of complicating factors from the statistical analysis. The largest effects present were for B7, R4, R9 when the high and low humidities are compared at the high temperature.

At lower concentrations and high humidity and temperature, the B7 readings were about 30 ppm higher than at low humidity and high temperature. R4 and R9 yielded more extreme results—over 35 ppm higher at 15 ppm for high humidity and high temperature than for low humidity high temperature and a bigger difference at higher concentration. For other monitors, the humidity effects were smaller in magnitude (less than 10 ppm) and were positive or negative. There was some inconsistency in the results for B7 and B8 in that B8 yielded much smaller humidity effects. The analyses of variance indicated that the higher humidity at higher temperature does not always have a statistically significant positive effect on all monitor readings, but it is rare that it has a significant negative effect when compared to the effect of lower humidity at the higher temperature. These conclusions on the importance of humidity at high temperature are based on the assumption of nonsignificant interaction between CH_4 level and the temperature-humidity factor and are also supported by the results of the final experiment discussed below.

TABLE IV. Effect of CO and CH_4 on Monitor Response

Monitor	CO*	CH_4*
T6	7.1%	9.8%
M10	6.6%	7.5%
R4	−9.0%	−10.4%
R9	−8.3%	−12.5%

*Percent bias caused by 1000 ppm CO or CH_4.

Examination of the data in Table IV indicated that both carbon monoxide and methane had little effect for most monitors. The data summarized in Table IV were collected at 40 percent RH and 23°C (75°F). The carbon monoxide effect showed up in the second factorial design experiment mostly through its interaction with temperature or with temperature and humidity at high concentration levels for some monitors, and, therefore, it is a complicated effect. In magnitude none of these approach the humidity effects for monitors B7, R4, and R9. Many of the monitors show evidence of such interactions. These interactions seem to reflect differences in response when carbon monoxide is present at the higher temperature. At low temperature the presence or absence of carbon monoxide does not lead to different response. Some monitors read higher with carbon monoxide present at high temperature; other monitors read lower.

The results of the second factorial design experiment suggest that monitor readings are significantly increased at higher humidity levels for monitors B7, R4, R9. For the other monitors, the effects vary. The effect of carbon monoxide appears to be related to temperature and humidity in a complicated manner. Because of confounding in the fractional factorial used in this experiment, the interaction effect of methane and temperature-humidity factor cannot be estimated. However, the results of the first factorial experiment, given above, combined with those of the experiment described next, suggest that any methane effect is small in comparison with the humidity effect. The fact that the reference conditions have the same moisture content as the low humidity at the higher temperature makes it possible to obtain a direct measure of the temperature effect—higher temperature (69°C) versus reference condition temperature (24°C). For every monitor except M10 and T6, application of a t-test indicates that the higher temperature leads to lower readings. How much lower varies considerably from one monitor to another. The effect of temperature is of limited use without consideration of the moisture level.

The final set of experiments was done at two different temperatures and a wide range of humidities. Table V presents the results of these experiments. The slope of the monitors' response

TABLE V. Response at Various Humidities at 24°C (75°F) and 49°C (121°F)

		24°C (75°F)						
		Humidity (% RH)						
Monitor	**Response***	**12**	**19**	**28**	**40**	**50**	**70**	**90**
G1	SLOPE × C − 0.8	0.96**	1.06	1.02	0.99	0.98	1.00	1.00
G3	SLOPE × C − 0.3	0.96	1.05	1.01	0.98	1.00	1.01	1.02
B7	SLOPE × C + 2.4	0.64	0.70	0.91	0.87	1.07	1.50	1.57
B8	SLOPE × C + 0.8	0.62	1.48	2.17	1.92	2.33	3.52	3.72
T6	SLOPE × C + 10.4	0.09	0.27	0.59	0.79	0.96	1.06	0.94
T5	SLOPE × C + 27.0	0.73	1.47	1.54	1.54	1.54	1.54	1.54
M2	SLOPE × C + 3.8	0.44	0.68	0.78	0.78	0.73	0.79	0.83
M10	SLOPE × C + 7.7	0.56	0.60	0.58	0.59	0.65	0.57	0.51
R4	SLOPE × C + 4.1	0.30	0.48	0.83	1.00	1.03	1.21	1.33
R9	SLOPE × C + 5.0	0.30	0.52	0.88	1.05	1.11	1.34	1.47

		49°C (121°F)		
		Humidity (% RH)		
Monitor	**Response**	**15**	**42**	**82**
G1	SLOPE × C − 0.8	0.87**	0.80	0.73
G3	SLOPE × C − 0.3	0.91	0.85	0.80
B7	SLOPE × C + 2.4	1.06	2.16	2.66
B8	SLOPE × C + 0.8	2.51	4.02	3.72
T6	SLOPE × C + 10.4	0.68	0.85	2.00
T5	SLOPE × C + 27	1.33	1.35	1.68
M2	SLOPE × C + 3.8	0.61	0.65	0.70
M10	SLOPE × C + 7.7	0.55	0.53	0.50
R4	SLOPE × C + 4.1	0.60	1.32	1.56
R9	SLOPE × C + 5.0	0.67	1.54	1.78

*In this table a curve of the form SLOPE × C + B (where C is the concentration, SLOPE is the slope, and B is the intercept) is fitted to the response of each monitor.

**The numbers in the body of the table are the SLOPE of response curve under conditions of the experiment. C = Concentration of H_2S (0–50 ppm).

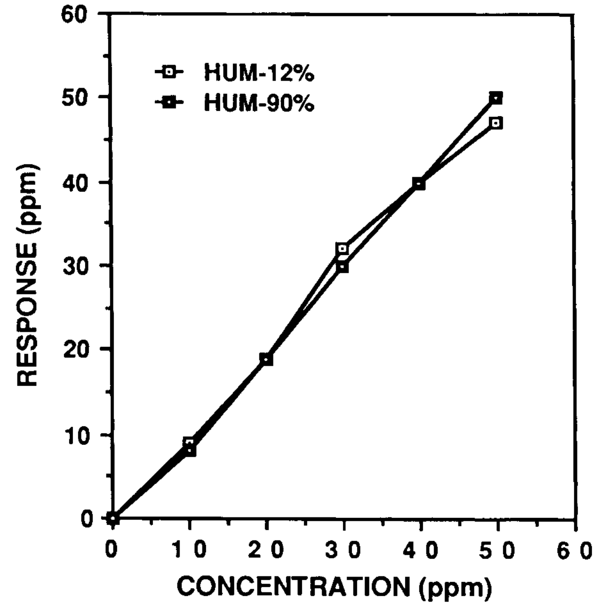

FIGURE 6. Response of G3 at room temperature for various humidities.

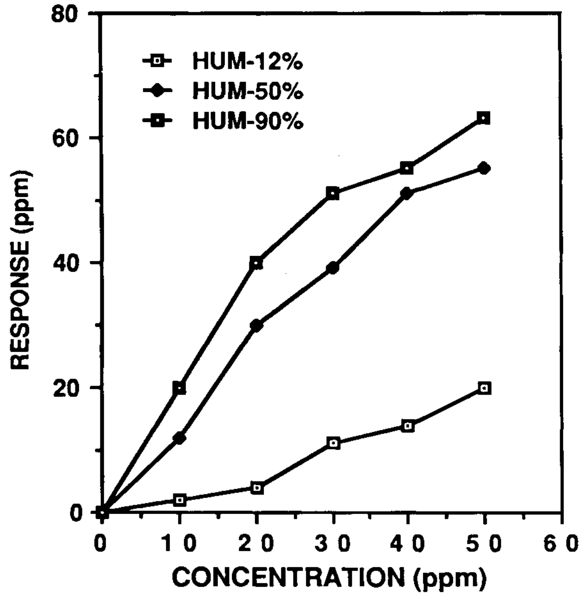

FIGURE 7. Response of R4 at room temperature for various humidities.

curves is given for the various temperatures and humidities studied. To determine the effect of humidity on the slope, all of the response curves at the various humidities were made to pass through the same intercept. All response curves were fitted as linear least squares. At room temperature, the G1 and G3 monitors showed very little change of response with humidity. As expected, the B7, B8, R4, and R9 monitors showed a very large effect due to humidity. Figures 6 and 7 show the response of G3 and R4 as a function of concentration at various humidities. G3 shows little effect, while R4 shows a large increase in response and exhibits more curvature in its response curve with increasing humidity in addition to an increase in slope. The effects with the T6, T5, M2, and M10 are somewhat less consistent and not very large. At 49°C (121°F), the G1 and G3 monitors showed measurable, but not large, effects due to humidity, which resulted in lower response. The B7, B8, R4, and R9 monitors showed very large humidity effects, which resulted in higher response.

Conclusions

Table VI summarizes the response characteristics of each type of monitor evaluated in this study. The table provides an assessment of the range over which a single response function can be used, an assessment of the stability of the response with time, the speed of response, the effect of changes in temperature on response, and the effect of changes in humidity under three different conditions. G1, G3, R4, and R9 are monitors which employ a two point calibration system and linearized output and which can provide a consistent response over some concentration range. The response is approximately linear (even if there is some contribution from nonlinearity). The outputs from G1 and G3 could be used directly in the range 0–100 ppm, but an output conversion system would have to be ordered for the digital display of R9 and R4 to obtain an output that could be conveniently recorded. Also, a two-piece line was needed for R4 and R9 over the entire range of 0–100 ppm. It appears that it is better to calibrate this type of monitor at the extremes in the concentration range to be measured. G1 and G3 were calibrated at 20 ppm and 100 ppm and gave a uniform response over the entire range. G1, G3, R4, and R9 also were better able to maintain calibration as a function of time than monitors employing a one point calibration. Therefore, useful concentration data could be obtained from these monitors under many conditions.

The only disadvantage of a linearized output is at lower concentrations (below 5 ppm) where the monitors (such as G3, G1, R4 and R9) with linearized outputs show little or no response. This is due to the way the signal from the sensors is linearized.

Also, the calibration of several of the monitors (especially B7, B8, R4, and R9) is affected by humidity. These monitors should be calibrated at the humidity encountered in the field. The humidity should not fluctuate widely if the calibration is to remain valid. Several monitors such as G1, G3, M2, and M10 did not show much of an effect due to changes in humidity. The microprocessor controller, such as that used with the G3 and G1 monitors, not only would make the output more useful but seems to result in a stable calibration. Regardless of the type of monitor used, a calibration schedule should be developed. The frequency of calibration would be determined by the observed calibration drift and the desired accuracy.

Recommendations

Any of the monitors could be used for alarm purposes which is the main application at this time for this type of monitor. This is due to good zero stability. Zero drift would not result in false alarms being generated. However, for some of the monitors, the span could drift considerably. In the worst case of span drift, a concentration of 50 ppm was required when the alarm level was set at 20 ppm so the monitor would alarm at high levels even if the span drifted.

Some of the monitors would have potential to give concentration measurement with some restrictions. For useful concentration data to be obtained, it would be necessary to have electronic linearization to obtain a useful output from the monitor. Electronic linearization apparently also resulted in better span stability and reproducibility for at least two brands of monitors (G1, G3, R4, R9). This requires a two point calibration which should cover the entire range of use of the monitor if concentration data are to be obtained over the entire range.

If the monitor is affected by humidity, the monitor should be calibrated at the humidity where it will be used. The humidity cannot change greatly if the concentration measurement is to remain accurate.

The monitor's accuracy would depend on the frequency of calibration. The G1 and G3 monitors could be calibrated monthly with about 20 percent maximum change. Others would presently require more frequent calibration. Experience will tell how often a given monitor will need calibration.

It is felt from this study that this type of monitor has potential for concentration measurement, but some improvements should be made. If the best feature of each monitor were somehow combined, then a more useful monitor that could be used for both alarm and concentration measurement could be developed. Several of the changes would be related to the operating conditions of the sensor. For instance, the sensor used with the R4 and R9 monitors resulted in very fast response but had a large

TABLE VI. Summary of Effects by Monitor Type

Monitor	Range	Stability	Speed	Temp	Hum1	Hum2	Hum3
G3, G1	0–100	20%	150	22%	30%	10%	15%
B7, B8	0–20 nonlin.	100%	19	56%	152%	144%	63%
T6, T5	0–20 nonlin.	100%	152	32%	27%	100%	68%
M2, M10	0–20	100%	123	14%	15%	39%	12%
R4, R9	0–40	50%	10	78%	282%	120%	83%

Range—Range in ppm over which a single response function can be used (nonlin. = nonlinearized output).
Stability—Maximum change in response with time over period of study.
Speed—Average time in seconds to reach 75% response (averaged over all concentrations).
Temp—Average effect of temperature on response (20°F to 157°F).
Hum1—Average effect of humidity on response (10% RH to 40% RH at 157°F).
Hum2—Maximum effect of humidity on response (75°F 12% RH to 90% RH)—Range/Average response.
Hum3—Maximum effect of humidity on response (121°F 15% RH to 82% RH)—Range/Average response.

humidity dependence. The fast response would make it very useful for alarm purposes.

The sensor of the G1 and G3 monitors resulted in a more stable response and was not as affected by humidity but was slower to respond. This would make it more useful for concentration measurement, but it would not alarm as quickly.

Perhaps a better compromise between speed of response and stability can be achieved. More extensive use of microprocessors could result in easier and more accurate calibrations and better linearity of response. Also, the microprocessor could be used for some simple forms of data analysis.

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