Evaluating performance characteristics of machine-mounted methane monitors by measuring response time

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ABSTRACT: Methane monitoring at the mine face is essential to assure a safe work environment in underground coal mines. Machine-mounted methane monitors must be used to continuously monitor methane levels during mining. Monitors used on mining machines must be approved by MSHA and properly maintained to provide protection for workers (30 CFR 75.342). To provide protection the instrument must give accurate readings of current methane levels. Accuracy is maintained by calibrating the instrument with a standard gas at least once every 31 days. Instrument "response time" determines how quickly measurements will change to reflect current concentrations. At present there are no criteria for measuring the response time for a machine-mounted methane monitor while underground.

This study examined a procedure for measuring the response time of a machine-mounted methane monitor. Response times were measured using methanometers obtained from three different manufacturers. The effects of the measurement technique and methanometer sensor head design on response time measurements are investigated. Techniques for reducing variation in response time measurements are discussed.

1 BACKGROUND

Federal regulations require that methane monitors be mounted on all continuous mining machines used in all underground mines. Each type of machine-mounted methane monitors must be tested and approved by MSHA before it can be used in a mine. The monitors are designed to alert face workers when methane concentrations reach 1 pct. The monitors must also warn workers and cut off electrical power to the machine when concentrations reach 2 pct (30CFR 75.342, (b)(1), (c)(1)).

After installation on the mining machine, the mine operator is responsible for periodically checking to assure the instrument is operating properly. Methanometer calibration must be checked and the results recorded at least once every 31 days (30CFR 75:342 (a)(4)). Calibration procedures are specified by the equipment manufacturer. In general they include exposing the instrument alternatively to an atmosphere containing no detectable methane gas, and then to an atmosphere containing a known concentration of methane. The instrument readout is set to zero while it is exposed to an atmosphere containing no gas or zero gas. The readout is set to the concentration of methane calibration gas (usually 2.5 pct) while exposed to the atmosphere containing the gas.

As a general guideline, a methanometer that reads +/- 0.1 pct of the zero gas and +/- 0.2 pct of the calibration gas is considered to be in calibration. The visual display should stabilize within 2 minutes after application of a gas. Application of current recommended techniques for single point calibration of methanometers is considered adequate for assuring the accuracy of machine-mounted methane monitors.

When a mining machine begins to cut coal, the methane concentrations at the face can rise and fall rapidly. If the methanometer response time is slow, the actual concentrations may be higher than the indicated readings. The monitor must not only read the methane concentration accurately but also respond quickly to changes in concentration in order to accurately reflect current methane concentrations and indicate potentially hazardous conditions.

The two most important factors that determine how quickly a machine-mounted monitor responds to gas released at the mining face are: 1) Sample transport time - The time for a volume of methane released from the coal face to reach the monitor sensor head, and 2). Monitor response time - The time for the monitor to respond to the methane after it reaches the monitor sensor head.

Sample transport time is affected mainly by the location of the sensor on the mining machine, the face ventilation system, and any mechanical barrier on the mining machine used to protect the sensor from dust and water. The effect of machine sampling locations on methane readings has been examined during NIOSH studies (Taylor, et al. 2001). Monitor response time can be affected by clogging of the sensor filter cap with dust, or normal aging of the sensor. A primary objective of this research was to measure monitor response times for machine-mounted methanometers using a technique that could be employed in an underground mine.

The response time for a methanometer is defined as the time interval for the methanometer output to change from a steady state reading in pure air to a steady state value for a calibrated gas of known concentration. In this paper response time is expressed as the time required for a instrument to display a percentage of the final output value (i.e. the concentration of the calibration gas). Since the sensor output approaches the final response limit asymptotically, the response time is usually defined as 90 percent of the final output value for the known gas concentration although lower percentages can also be used to define response time. For example, if 2.5 percent calibration gas is used, the 80-pct-response time (T80) is the time required for the concentration to reach 2 pct.

2 TEST PROCEDURES

To measure response time the instrument sensor head is first exposed to zero gas and then, instantaneously, exposed to the presence of a constant concentration of a calibration gas. Several techniques have been recommended for measuring response time in certification agency laboratories, but none of them are practical to use underground due to equipment and manpower requirements. For measuring response time underground some technique is needed that will allow application of calibration gas without requiring that the sensor head be removed from the mining machine. The technique used to make response time measurements should: 1) Designed for use by the industry miners or MSHA inspectors while working at the underground face, and 2) Provide results accurate and precise enough to indicate if methanometer performance is acceptable or has deteriorated to the degree that the instrument is no longer capable of providing adequate warning for the face workers prior to the build up of potentially explosive mixtures of methane and air in face areas.

3 INSTRUMENTATION

Methanometers were obtained from three different manufacturers. In this report, the methanometers are identified as "Monitor A," "Monitor C," and "Monitor G." Each methanometer includes a readout unit, power supply and sensor head. A sensor head from each of the manufacturers is shown in Figure 1. Three identical sensor heads were obtained from each manufacturer for use with the corresponding power supply and readout unit.

The basic components of the sensor head (See Fig.2) include: 1) the dust cap that includes screen and baffles to help prevent contamination of the sensor elements with dust and water, ("... A suitable filter on the sampling intake to prevent dust and moisture form entering and interfering with normal operation." (30 CFR § 27.22). 2) A porous flame arrester that covers an internal chamber, and 3) Sensor elements, where methane gas is oxidized.

All three manufacturers use catalytic heat of combustion type sensors. When methane reaches the sensor elements it oxidizes on the catalytic element. The oxidation generates heat, which upsets the electrical balance of a Wheatstone Bridge, sending a voltage signal to the monitor unit. The voltage is then converted to percent methane.

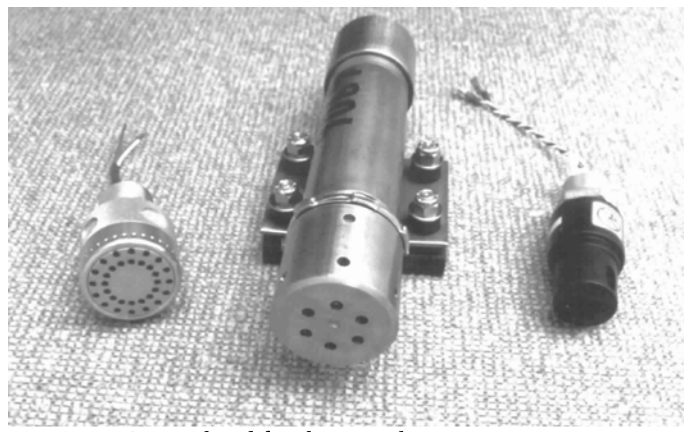

Figure 1. Sensor head for three methanometers.

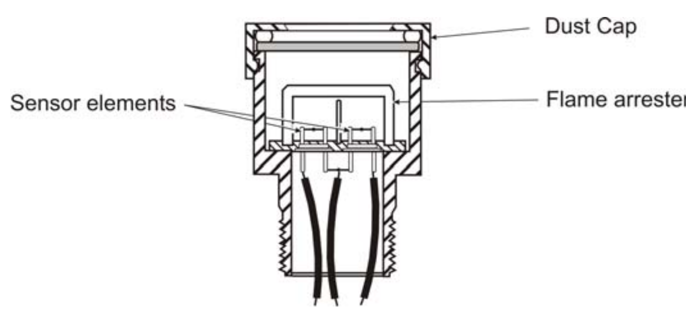

Figure 2. Basic components of sensor head.

4 RESPONSE TIME MEASUREMENTS

For these tests, response time was measured using a large display digital stop watch, a cylinder of 2.5 pct calibration gas, a calibration cup for delivering gas to the sensor head, and a flow meter for monitoring calibration gas flow. Before making a measurement, gas flow was directed through the calibration cup at the rate recommended by the manufacturer for calibration. The measurement began when the stopwatch was started (time zero) and the calibration cup was placed over the sensor head. Two observers independently recorded concentrations at 5-second intervals from the monitor readout and a digital stopwatch. Measurements were made every five seconds until the values equaled the calibration gas concentration (2.5 pct). Each test condition was repeated at least one time. Results from the two observers and repeat tests were averaged to determine response times.

Response time curves were drawn using the percent methane or voltage data from the methanometer readouts and the elapsed times obtained with the stopwatch. Each measured concentration in percent methane was divided by 2.5 (the percent methane concentration of the calibration gas) to give the response percentages. The response curve for each methanometer was obtained by plotting the elapsed time versus the response percentages. The response curves shown in Figure 3 represent the average responses for all tests with the three sensor heads. The 40, 80 and 90 pct response times determined from the response curves are given in Table 1. The 90-pct response times frequently are used as the criteria for evaluating performance of air sampling instruments. The 80 and 40 pct response times correspond to 2 and 1 pct concentration readings, when using the 2.5 pct calibration gas. Alarm signals must be provided by the methane monitors whenever methane concentrations reach either 2 or 1 pct methane.

Table 1. Response time for three monitors.

Response, pct	Monitor A Time (sec)	Monitor C Time (sec)	Monitor G Time (sec)
40	13	14	14
80	23	30	28
90	29	40	36

Currently there are no MSHA written response time criteria for methanometers, which are mounted, on mining machines. The response curves and data in Table 1 show that the response times varied for the three different methanometers. Response times vary for different reasons. After use underground, response times may vary because of aging of the sensor element, and exposure to dust and water in the mine environment. The instruments used in these studies were practically new and clean. Additional testing was conducted to determine what factors might cause differences in response times for new instruments. Factors related to the measurement technique and instrument design were also examined.

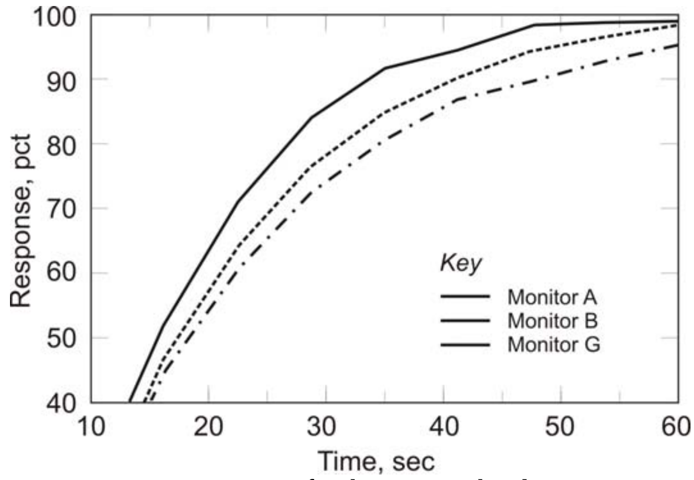

Figure 3. Response curves for three sensor heads.

5 EVALUATING RESPONSE TIME MEASUREMENT TECHNIQUE

To make response time measurements underground, the technique needed to be simple and require minimal equipment. The measurement technique was designed to reduce variation in the test results. Each methanometer was calibrated prior to making response time measurements. Calibration procedures were similar to those recommended by the manufacturer. The same cylinder of 2.5 percent methane calibration gas was used for all tests. Calibration does not affect instrument response time, but it is important to calibrate the instrument in order to determine the final output value for the response time. (In this case 2.5 pct methane).

5.1 *Data Acquisition*

The methane sensor head provides a continuous voltage signal that is proportional to the methane concentration. Underground the only way to observe the sensor head output is with the visual display. To simulate response time measurements underground, methane concentrations were obtained by two observers who recorded the methane concentrations from the visual display every 5 seconds. The two observers recorded the data independently, but concurrently. There was a high correlation between the data collected by the two individuals.

Above ground it is possible to disassemble the sensor head for monitor A and G and record the output signal directly. The output signals from monitors A and G were recorded every ½ second using a computer-based data acquisition system while, concurrently, the two observers recorded the voltage signal from the sensor head every 5 seconds using a digital voltmeter. All voltage readings were converted to the corresponding concentrations in pct methane and the response percentages plotted versus elapsed time. The response curves (Fig. 4), based on the ½ and 5-second readings, were very similar.

Therefore, the collection of data by the observers at 5-second intervals did not cause differences in the response time measurements.

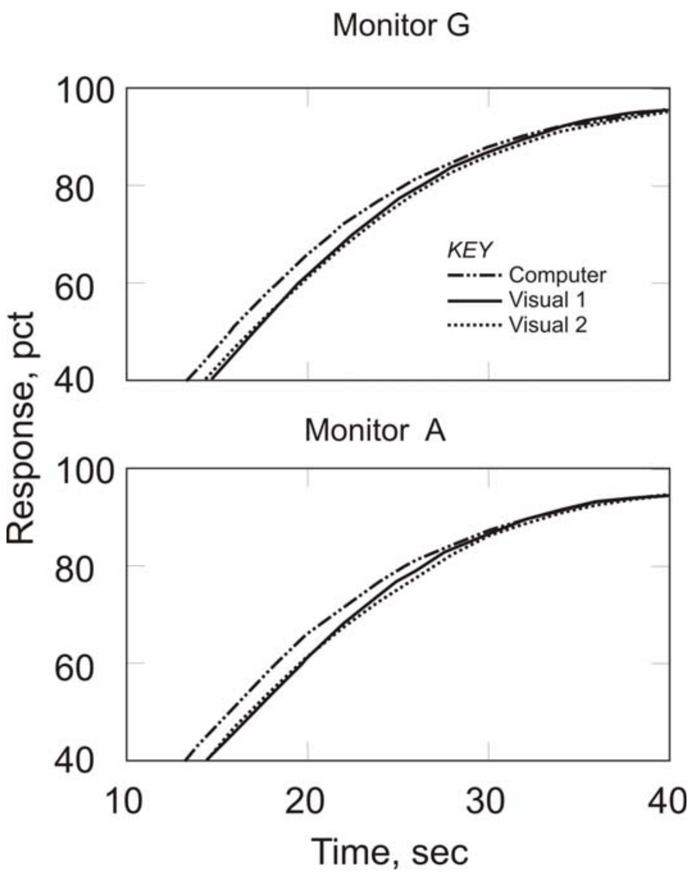

Figure 4. Comparison of response time data obtained with computer and visual observations.

5.2 *Control of Gas Flow Rate*

Increasing gas flow rate through the sensor head will reduce the time it takes for gas to reach the sensor elements. The effect of flow rate on response time was demonstrated by applying the calibration gas at flow rates 40-pct greater, equal to, and 40 pct less than the recommended calibration gas flow. Only one of the sensor heads for each of the methanometers was used for these tests. The response times for each of the monitors decreased as the flow rates increased (Table 2).

During testing the effects of gas flow rate on response time was minimized by maintaining the flow rate as close as practical to the recommended calibration flow (0.1 lpm for monitor A and 0.5 lpm for monitors C and G). Flow rates were monitored and adjusted using Dwyer Visi-Float flowmeters [1] (0.06 to 0.5 and .15 to 1 lpm ranges) and an inline flow regulator to dampen flow fluctuations. A calibration gas flow of 0.500 +/- .05 lpm was maintained during tests with monitors C and G, and 0.100 lpm +/- .02 lpm for monitor A. These small variations in flow did not have any measurable effects on response times. Gas flow rates were checked before each test and adjusted when necessary.

[1]Identification of manufacturer does not imply endorsement by NIOSH

Table 2. Effect of calibration gas flow rate on response time (seconds).

Monitor A

	Pct Response		
Flow rate (m1/min)	40	80	90
60	19	35	47
100	14	28	37
140	11	20	26

Monitor C

	Pct Response		
Flow rate (ml/min)	40	80	90
300	20	45	60
500	13	26	34
700	10	19	24

Monitor G

	Pct Response		
Flow rate (ml/min)	40	80	90
300	20	35	47
500	14	26	33
700	13	25	31

6 EVALUATING SENSOR HEAD DESIGN

Monitor response time has been defined as the time for the monitor to respond to the methane once it reaches the methanometer sensor head. Specifically the sensor head design could affect how long it takes for the gas to travel through the sensor head to the sensor elements. Design features of the sensor heads that could affect response time were examined.

The three cross sectional drawings in Figure 5 show the basic internal configurations of each of the three sensor heads tested. The sensor heads are shown with the calibration cups attached. Arrows show the most likely path the calibration gas would take as it enters the sensor head from the calibration cup, travels through the sensor head to the sensor elements, and finally exits the sensor head. The internal design determines how far the gas must travel through the sensor head before reaching the sensor elements. In general the greater the distance, the longer the response time.

The response time is also affected by the direction of the gas flow as it passes through the sensor head.

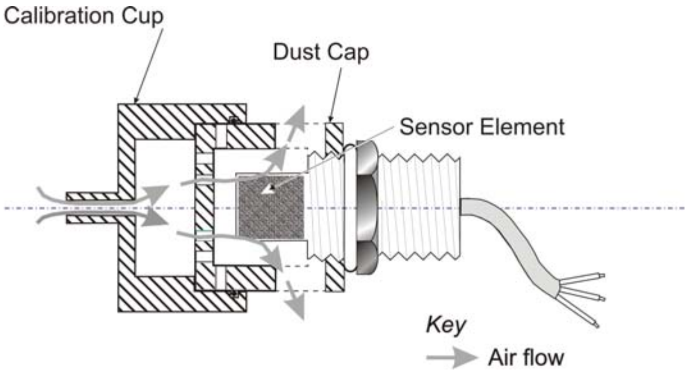

Figure 5. Sensor head for methanometer A.

Flow direction is affected by the baffles and screens as well as the locations where the gas exits the sensor. Gas enters each of the sensor head through holes in the top and or sides of the filter caps. Flow will generally be toward the exits holes, which is the path of least resistance. In sensor head A (Fig. 5) the exit holes are located in the side of the dust cap, below the level of the sensor element. In sensor head C (Fig. 6) the exit holes are in the top of the calibration cup, above the level of the sensor element. Exit holes for sensor head G (Fig. 7) are in the sides of the calibration cup, above the level of the sensor element Changing the location of the holes where the gas exits the sensor head may affect response time by varying the amount of gas that passes over the sensor elements.

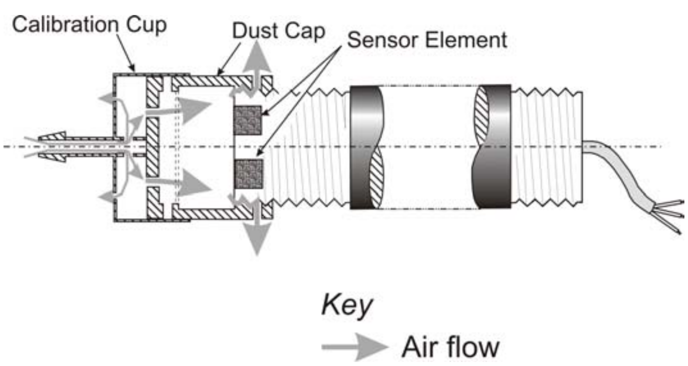

Figure 6. Sensor head for methanometer C.

Sensor head C was used to study the influence of exit hole position and flow direction on response times. With this sensor head, most of the gas exits the sensor head through three holes located in the top of the calibration cup (See Fig. 6). There are three holes near the bottom of the dust cap. When the dust cap is only screwed part way onto the body of the sensor head (location A), the holes are above the threads and open to the inside of the sensor body (Fig. 8A). At this position the holes are near the location of the sensor elements. With the cap turned all the way onto the body of the sensor cap (location B), the three holes are over top of the threads (Fig. 8B).

Response times were measured with the dust cap positioned so that the holes were either above the threads (location A1), or over top of the threads, (location B). The response curves in Figure 9 show that the response times were much shorter when the dust cap was at location A and the holes provided exit locations for the gas flow.

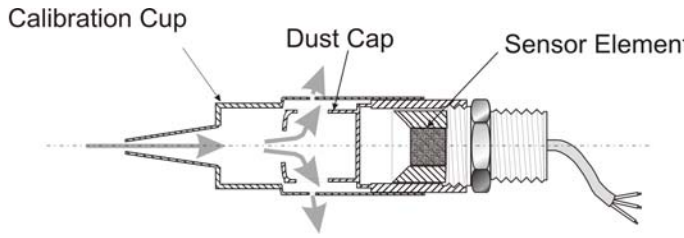

Figure 7. Sensor head for methanometer G.

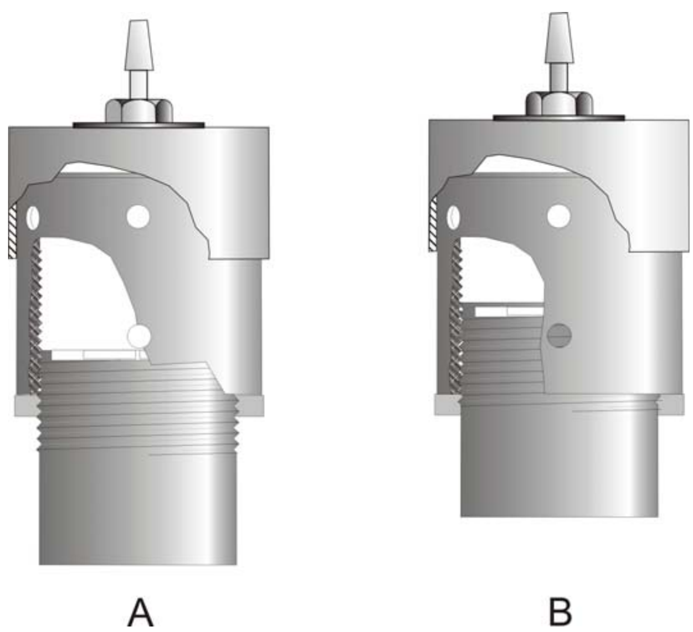

Figure 8. Dust cap positions tested for sensor head C.

With the dust cap at location B, some of the gas would have leaked around the cap threads even though the holes were covered. To determine what effect this leakage would have had response times a third series of the tests was conducted with the cap in location B and the threads sealed with Teflon tape. Response times were slower when the threads were sealed (Fig. 9). Sealing the threads forced all airflow to move toward the holes in the top of the calibration cup and away from the sensor elements. Leakage around the threads allowed some of the gas to pass by the sensor elements.

Tests were conducted with the holes at the top of the calibration cup covered with tape, and uncovered as during the prior tests. The dust cap was positioned so that the bottom holes in the dust cap were over the threads, but the threads were not sealed. The response curves (Fig.10) show that response times were shorter when the exit holes in the top of the calibration cup were covered. Covering the holes forced the gas to exit around the threads and past the sensor elements. Flow direction in the sensor head was again the factor affecting variation in the response times.

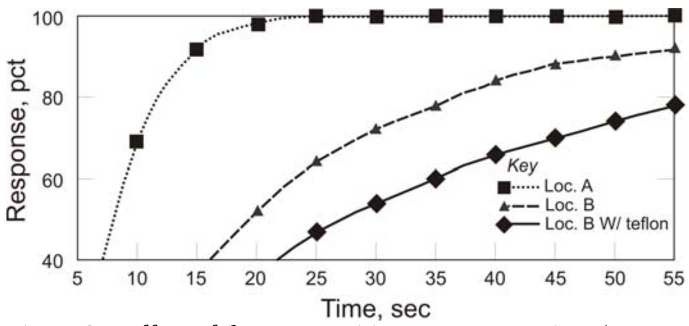

Figure 9. Effect of dust cap position on response time (sensor C).

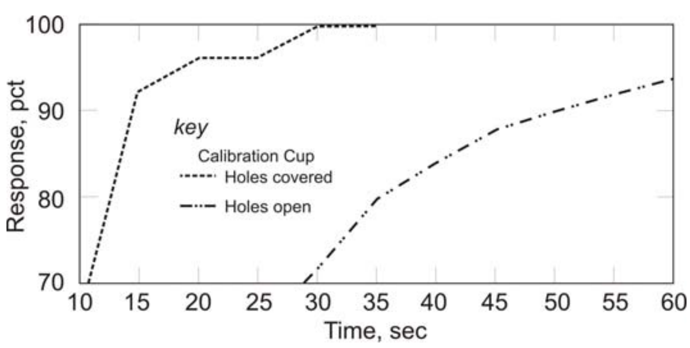

Figure 10. Effect of sealing holes in calibration cup (sensor C).

7 DISCUSSION AND CONCLUSION

This research demonstrated a technique for measuring response times underground. Response times were measured for three types of methanometers that are currently approved for use underground. Response curves were drawn to compare instrument performance. The curves were similar to the "S shaped curves"[2] obtained with other air monitoring devices.

A difference in response times between instruments was attributed primarily to differences in the designs of the sensor heads. The different configurations caused changes in flow patterns in the dust caps. Tests were conducted to show how changing flow patterns affected response times. In general shorter response times are more desirable for methane sampling instruments. However, the purpose of these tests was not to modify methanometer design, but response times for the methanomters. When used and properly maintained in the mine environment, the methanometers can help to ensure a safe work environment for underground workers.

[2]Introduction to Nonlinear Differential and Integral Equations, H. T. Davis, Dover Publications, NY, 1962

The primary reason for measuring response times is to document changes in methanometer performance that occur during normal usage. Normal usage includes aging of the methanometer and exposure of the sensor head to dust and water. When normal usage results in longer response times, the level of safety provided to the worker can be reduced. The data obtained from this study can be used as basis for criteria to evaluate instrument performance using response time measurements.

The ranges of response times measured for each of the three methanometers are typical for new instruments. Any increases in response time beyond this range could indicate a deterioration in instrument performance and the need to either, provide routine maintenance, repair, or replace the instrument.

For these tests, methanometer performance was determined by either comparing the response time curves (which were plots of response percentages versus elapsed time from application of the calibration gas), or the 90, 80, or 40 response percentages for the final output values of the calibration gas. The 40 and 80 percent responses correspond to methane concentrations of 1 and 2 pct respectively because 2.5 pct methane calibration gas was used. As long as a 2.5 pct calibration gas is used, the entire response time curve would not have to be drawn to determine the 40 or 80 pct response times. Instead, the time from application of the gas, until a reading of 1 or 2 pct could be measured directly. Moreover, the instrument alarms for 1 or 2 pct could be used to indicate when the concentration had reached the 40 or 80 pct response times.

8 FUTURE WORK

8.1 *Flame Arrester Permeability*

The research investigated the effects of the travel path on the response times, but the movement of the gas through the flame arrester was not evaluated. Porous metal flame arresters surrounded each of the sensor elements. The time required for gas to travel though the flame arresters is not known but would vary with the porosity and thickness of the metal. During these tests the porous metal was clean and the time for the gas to pass through the flame arresters considered small. Future testing will be conducted to examine how exposure of the flame arrester to dust and water affects permeability and travel time for the gas.

8.2 *Effects of Exposure to Dust and Water*

Exposure to dust and water can also affect the permeability of screens in the sensor head. Water can damage sensor elements and dust can block holes that allow movement of gas in and out of the sensor head. It is not possible to design a laboratory test to evaluate the effects of dust and water on methanometer performance because exposure to these airborne contaminants is different for each mining situation. Underground testing that includes periodic measurements of response time for the machine-mounted methanometer should be conducted. Using either total dust exposure or feet of mining advance as an index of exposure, the effects dust and water response times would be determined.

8.3 *Gas Application without Calibration Cup*

Measurements made during these tests required the use of calibration gas, which was applied to the sensor head through a calibration cup. Applying gas through the calibration cup affected the flow patterns in the sensor head. In the mine environment gas would enter the sensor head via convection and diffusion, and flow patterns would not be the same as during response time measurements. Additional testing will be conducted to determine if response times measured by applying calibration gas with and without the calibration cup are significantly different. The three sensor heads will be placed side by side in a sealed box and exposed to a step input of a methane gas. The response times will be compared to the times obtained using the calibration cup.

8.4 *Effect of Travel Time on Methanometer Response*

The location of the instrument on the mining machine and the amount of instrument shielding are important factors. Increasing the distance of the methanometer from the face and increasing shielding can reduce methanometer exposure to dust and water but it can also increase response time due the additional time required for methane to travel from the face to the sensor head. Measurements will be taken in a model mine to compare times for gas to travel from a gas release point at the face to different sampling locations on a model-mining machine.

REFERENCES

Taylor, C.D., Thimons, E.D. & Zimmer, J.A. 2001. Factors affecting the location of methanometers on mining equipment. Proceedings: 7th International Mine Ventilation Congress, June: 683-687.

U.S. Code of Federal Regulations. Title 30 - Mineral Resources, Part 75