# Use of a Test Box to Measure Response Times for Machine-Mounted Monitors

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ABSTRACT: A technique for use in underground coal mines measures the response times of machine-mounted methane monitors. This technique uses a calibration cup to deliver gas to the sensor head to measure response times. For comparison, in the current study, response times were measured by placing methane sensor heads in a specially designed test box where they were exposed to an atmosphere containing a constant concentration of methane. Response time readings measured in the test box were shorter than the readings obtained using the calibration cup. The response times measured in the test box were comparable for sensors from three different manufacturers. The effects of dust cap and flame arrestor design on response times were also evaluated using the test box.

## 1 INTRODUCTION

During coal mining, methane concentrations are usually highest near the face where the continuous mining machine is extracting coal. To ensure the safety of workers, methanometers are mounted on the mining machine to continuously monitor methane levels. Each type of machine-mounted methane monitor must be tested and approved by MSHA (30 CFR 27.22 through 27.40) before it can be used in a mine. The monitors are designed to alert face workers when methane concentrations reach 1 pct (30 CFR 75.342, (b) (1)). The monitors must also warn workers and cut off electrical power to the machine when concentrations reach 2 pct (30 CFR 75.342 (c) (1)).

Clearly, the methanometer can provide protection only if it accurately records the methane readings. Accurate readings require the instrument to be calibrated and require that it respond quickly to changes in concentration. Calibration procedures are specified by the equipment manufacturer. The mine operator is required to check the methanometer calibration at least once every 31 days (30 CFR 75.342 (a) (4)).

Currently there are no criteria for the measurement of methanometer response times or response time limits. The response time for a methanometer is defined as the time interval for the methanometer output to change from a steady state or zero reading in pure air to a given percent value of the final steady state reading upon application of a calibrated gas. Since the sensor output approaches the final response limit at a steady state, the response time is usually defined as 90 pct of the final output value for the known gas concentration, although lower percentages can also be used to define response time.

To measure response times 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. The instrument response reading is then measured as a function of time from initial exposure to the gas. Techniques that have been described for making response time measurements with gas sampling instruments are not practical for use in an underground mine
Environment (Hughlett 1982, Foster-Miller 1985)

During an earlier NIOSH study to measure response times (Taylor 2002), calibration gas was applied directly to the sensor head through the manufacturer-supplied calibration cup at a stated flow rate. Use of the calibration cup allowed the delivery of a known concentration of methane to the sensor head with minimum interference from the surrounding atmosphere and provided a means for measuring response times on equipment underground. One problem with this technique is that the installation of the calibration cup over the dust cap alters the normal airflow around and through the sensor head. Therefore, a technique for measuring response time that does not require use of the calibration cup was desirable for comparison.

This report describes a laboratory technique for measuring response time in a test box that does not require the use of a calibration cup. In the test box, response times were measured by exposing methane sensor heads supplied by three different manufacturers to a constant methane concentration. Response time measurements obtained in the test box and with the calibration cups are compared.

## 2 TEST PROCEDURE

### 2.1 *Methanometers*

Methanometers obtained from three different manufacturers, which were also used during an earlier study, are identified as "Monitor A," "Monitor C," and "Monitor G." Each of the monitors is approved by MSHA (CFR 30, part 27) for use on mining equipment and included a visual readout unit and power supply provided by the manufacturer. Three identical sensor heads were obtained from each manufacturer.

Each manufacturer's sensor head design was different but the basic components included a dust cap, a porous flame arrester that covers an internal chamber, and a sensor element. The sensor head for each type of monitor used a catalytic heat of combustion sensor to measure methane. Figure 1 shows one sensor head obtained from each of the three manufacturers.

### 2.2 *Test Box*

A 14- x 14- x 14- inch plywood box was built to contain a methane-air mixture (see figure 2). A bracket mounted near the center of the box held a single sensor head during testing. The box had a removable top that allowed the placement and

Figure 1. Sensor heads for monitors A, C and G.

removal of the particular sensor head being tested. A foam seal on the top helped to reduce leakage of gas from the box. Methane was injected and air samples withdrawn through plastic hoses that were inserted through holes on one side of the box. Electrical cables to power the sensor heads and transmit data also passed through holes in the opposite side of the box. Two 4-inch fans attached to the bottom interior of the box were used to mix the injected methane gas with box air.

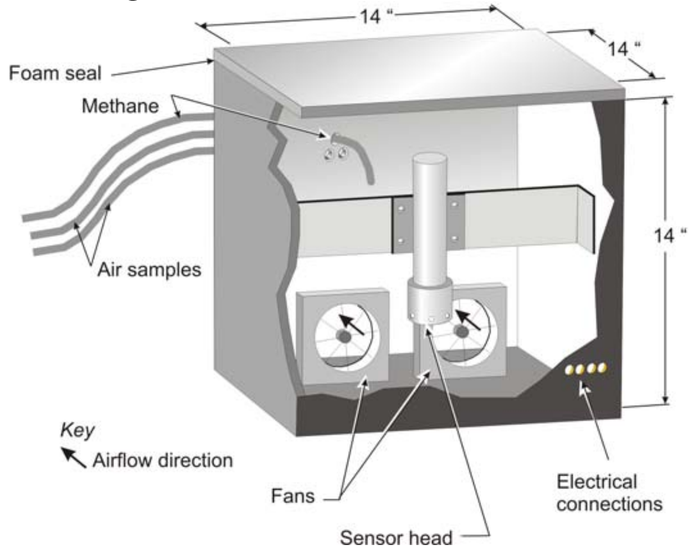


Figure 2. Test Box.

### 2.3 *Gas Delivery and Mixing*

The three sensor heads were individually exposed to gas-air mixtures in the test box. Methane (99 pct) was injected into the box using a plastic syringe Super Syringe Hamilton Co Reno NV that had markings to indicate volumes from 0 to 1500 cc. The gas was transferred from a cylinder to the syringe (see figure 3). The methane flowed through the plastic tubing into the water-filled container for approximately 30 seconds prior to the syringe being filled. The end of the syringe was capped until the gas was injected into the box. Approximately 4 seconds were

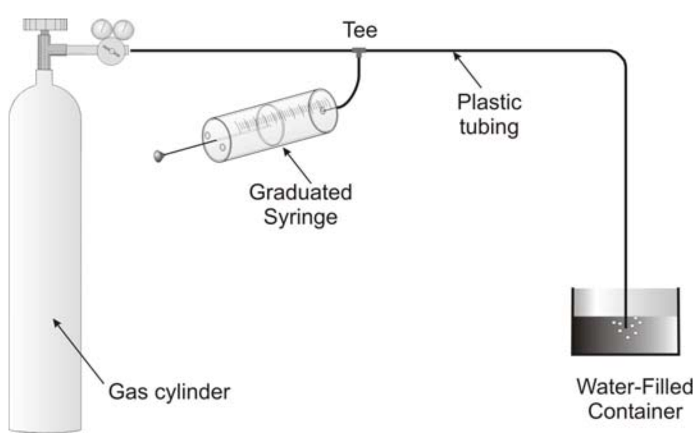


Figure 3. Apparatus for filling syringe.

required to manually depress the plunger and transfer the gas from the syringe to the box.

The quantities of methane gas injected into the box were varied (300 to 1200) and the average concentrations in the box measured with a Horiba Model PIR-2000 infrared gas analyzer. Figure 4 shows the relationship between the quantity of methane gas injected into the box and the final average concentration. For most tests, 1000 cc of gas were injected into the box resulting in concentrations between 2.0 and 2.5 pct methane.

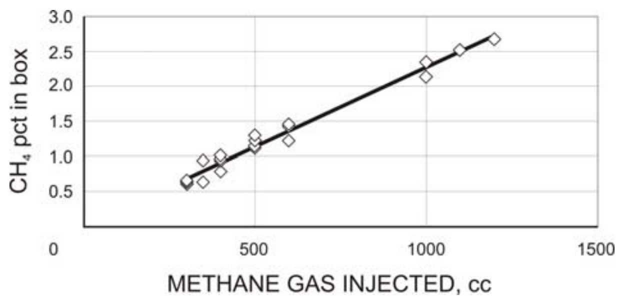


Figure 4. Relationship between gas injected and concentration in box.

The Horiba Model PIR-2000 infrared gas analyzer, which has a very fast response rate for methane gas, was also used to measure how quickly concentration increased in the box following gas injection and how long that concentration was maintained. Air samples from the box were transferred to the Horiba analyzer gas cell using a MSA Flowlite air pump (see figure 5). The pump was operated at 1.5 lpm and has inlet and outlet ports that allow the direct transfer of gas between the box and the Horiba. The tubing between the box and Horiba was as short as practical to minimize transport time. The output signal from the Horiba, which is proportional to the methane concentration, was recorded by a computer-based data acquisition system

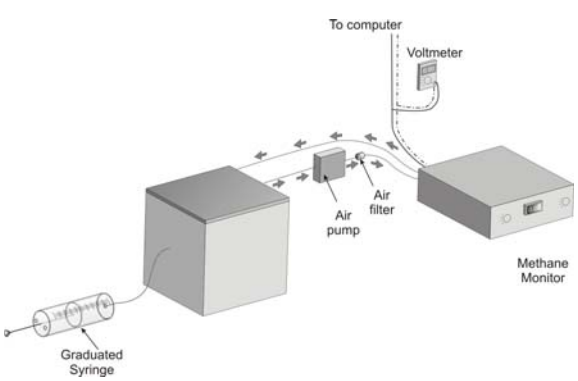


Figure 5. Test setup with Horiba monitor.

Figure 6 shows the response time measurement obtained with the Horiba monitor for gas injected into the test box at time zero. Concentrations reached 90 pct of their maximum value in less than 9 seconds and 99 pct of final value in less than 10 seconds. The 4-second delay between gas injection and

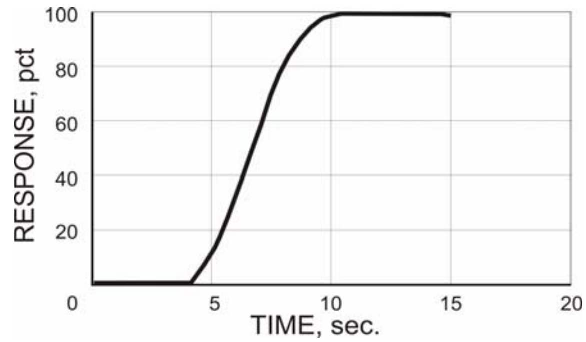


Figure 6. Response curve measured with Horiba monitor.

and any signal response was probably due to the time required for the gas to travel from the box to the Horiba sensor. Assuming this delay in response was due to gas travel time, concentrations in the Horiba monitor reached 99 pct of their final level less than 6 seconds after the gas was injected. Methane levels in the box decreased about 2.5 pct per minute after reaching their maximum level due to leakage from the test box.

### 2.4 *Data Acquisition*

Before each series of tests with a sensor head, instrument calibration was checked using 1 pct calibration gas applied by the manufacturer-supplied calibration cups. To measure response time the sensor head was placed in the bracket, the lid installed, and the fans started. After confirming a zero reading on the monitor readout, the gas was injected. A large display stopwatch was started when the gas was injected. Two observers independently recorded the methane concentrations at 5-second intervals. Data were collected for 2 to3 minutes after injection of the gas and each test was repeated one time. The response time for each sensor head was based on the average of concentrations measured by both observers during the two tests. Readings for the three sensors from each manufacturer were averaged to determine response times.

## 3 RESULTS

### 3.1 *Response Time Readings*

The response curves (see figure 7) for each type of methanometer monitor were drawn by plotting the elapsed time versus the response percentages. The response percentages were calculated by dividing the average methane concentration for each 5-second sampling interval by the maximum methane concentration measured for that test. The response curves shown in figure 7 are based on the average responses for all tests with the three identical sensor heads. The 90, 80, and 40 pct response times, which were determined from the response curves, are given in table 1. Table 1 also includes the response time

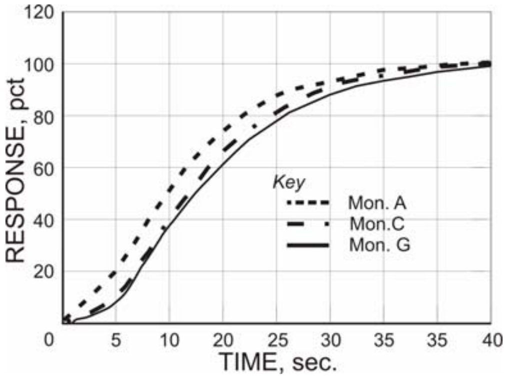


Figure 7. Response curves for three monitors.

Measurements made earlier using the calibration cup. For these tests 2.5 pct calibration gas was used. The 80 and 40 pct response times correspond to 2 and 1 pct methane readings when using 2.5 pct gas.

Table 1. Response time, Calibration Cup, and Box.

| Resp. Time | Monitor A | | Monitor C | | Monitor G | |
|---|---|---|---|---|---|---|
| | Cal. Cup | Box | Cal. Cup | Box | Cal. Cup | Box |
| | Sec | Sec | Sec | Sec | Sec | Sec |
| 90% | 29 | 23 | 40 | 25 | 36 | 29 |
| 80% | 23 | 17 | 30 | 20 | 28 | 21 |
| 40% | 13 | 8 | 14 | 10 | 14 | 10 |

## 4 DISCUSSION

### *4.1 Calibration cup*

For each type of monitor tested, response times were shorter when measured in the box. Part of the differences in response times can be attributed to how fast the gas passes through the sensor head. Flow rates recommended by each manufacturer were used for the calibration cup tests. Gas must travel through the dust cap and flame arrestor to reach the catalytic head of combustion sensor whether the measurements are made with the calibration cup or in the box. However, the airflow paths are different depending on whether a calibration cup is or is not installed over the dust cap.

Figure 8 shows a cross-sectional view of each sensor head with the calibration cup installed. The arrows show the likely path the calibration gas takes 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. Installing the calibration cup on the dust cap forces the air to enter the holes in the top of the cap and exit through holes in the side.

Figure 9 shows the same sensor heads with the calibration cups removed from the dust caps. Without the cup, air can enter or exit through holes in the sides and top of the dust cap. The improved exchange of air provided by calibration cup removal was probably a factor in the reduced response times.

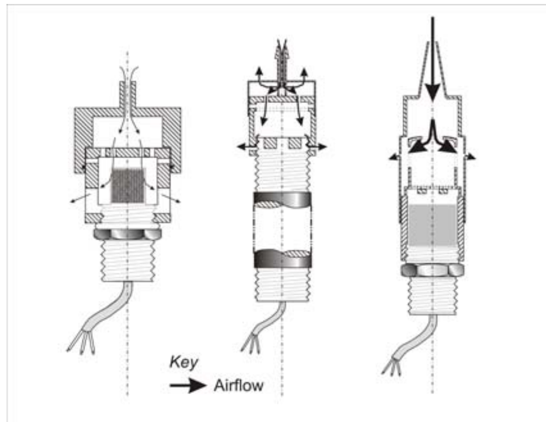


Figure 8. Sensor heads (monitors A, C, and G) with calibration cup attached.

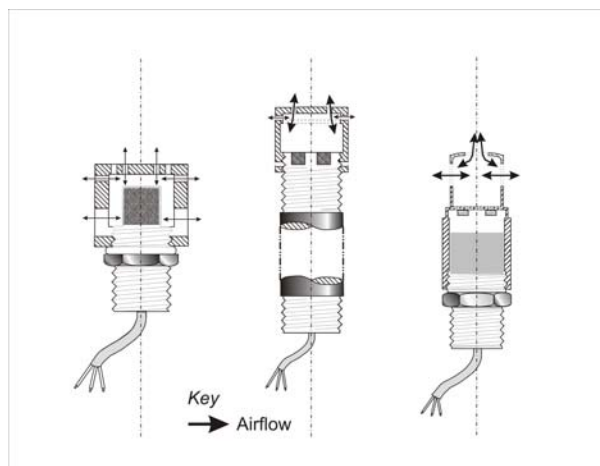


Figure 9. Sensor heads (monitors A, C, and G) with calibration cup removed.

### *4.2 Dust cap*

Response time measurements were made in the box, as described above, except that the dust caps were removed. Dust caps must be installed on the sensor head when operating the machine-mounted methanometers underground. Comparative measurements were made without the dust cap to estimate how much of the response time is due to gas flow through the cap. The 90, 80, and 40 pct response times for each monitor, with and without the dust caps in place, are given in Table 2. For all response times a large part of the total response time can be

Table 2. Response Time Cap On and Cap Off.

| Resp. Time | Monitor A | | Monitor C | | Monitor G | |
|---|---|---|---|---|---|---|
| | Cap On | Cap Off | Cap On | Cap Off | Cap On | Cap Off |
| | Sec | Sec | Sec | Sec | Sec | Sec |
| 90% | 23 | 12 | 25 | 4 | 29 | 14 |
| 80% | 17 | 9 | 20 | 3 | 21 | 10 |
| 40% | 8 | 4 | 10 | 2 | 10 | 4 |

attributed to the time required for the gas to flow through the dust cap.

### *4.3 Ambient air velocity*

The amount of air moving in and out of the sensor head is affected by the ambient air velocity and orientation of the sensor head relative to the flow. Flow conditions in the box were measured at three locations (see Figure 10) using a hot wire anemometer. Flows measured in the vertical direction varied from 35 to 45 fpm and from 65 to 150 fpm measured in the horizontal direction. These were within the range of conditions that would be encountered near the head of an operating mining machine.

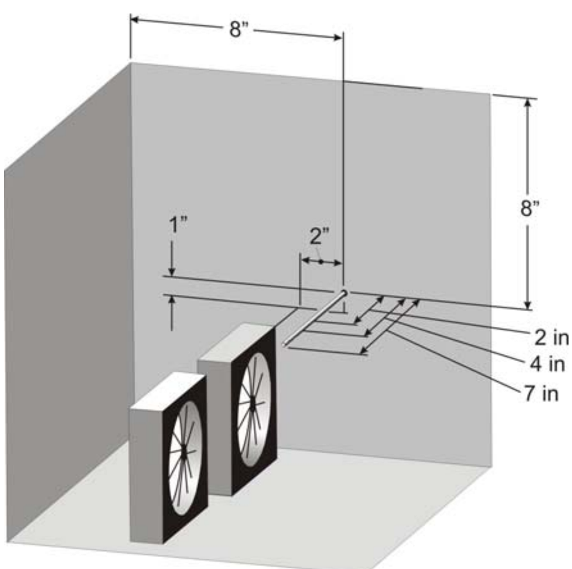


Figure 10. Flow measurement in test box.

### *4.4 Flame arrestor*

The 90 pct response times for the three monitors varied from 4 to 14 seconds when the dust cap was removed. The differences in time are likely due to how quickly the gas traveled through the flame arrestor and reached the sensor elements. The time for the instrument to electronically record voltage changes due to the heating of the sensing element would be similar for each instrument.

The flame arrestors used with monitors A, C, and G are made either of porous metal or a fine mesh screen. The sensor elements are located close to the flame arrestors. Monitor A has a cylindrically shaped porous metal filter that surrounds the sensor element. In Monitor C, two small round porous metal plugs are located in a plate above the sensor elements. In Monitor G, a screen is located above the sensor element.

## 5 CONCLUSIONS

Response time readings were made by placing methane monitors inside a 14-inch square fabricated test box and exposing them to an atmosphere containing methane. These readings were compared to response times measured earlier by applying methane directly through the calibration cup to the sensor head. Use of the calibration cup was designed for underground use where the technique must be simple and require minimal equipment. The use of the calibration cup is a satisfactory method for making response time readings underground. Obtaining this data periodically will also help to indicate if instrument performance has deteriorated and whether there is need for repairing or replacing the instrumentation.

Use of the test box provided a way to expose the sensor heads to gas without using the calibration cup, and also provided conditions that closely simulate underground airflow conditions on a mining machine where a methane monitor is mounted. The response time readings made in the box were approximately equivalent for all three monitors and were faster than the response measurements made with the calibration cups.

The effects of dust cap and flame arrester design on response time were also examined. It was found that shortening response time is one way to improve instrument performance, and response time is affected by the design of the dust cap and the flame arrestor. Shortening the flow path through the dust cap and decreasing the porosity of the flame arrestor might shorten response time. However, it must be kept in mind that the dust cap helps prevent water spray and dust from contacting the sensor element and the flame arrestor prevents the propagation of any flame outside the sensor head. Therefore, no changes should be made to the dust cap or flame arrestor that would lessen the protection of the sensor element.

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