Use of infrared sensors for monitoring methane in underground mines

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ABSTRACT: Federal regulations require the use of methane monitors on all mining machines. All machine-mounted methane monitors currently used in underground coal mines rely on catalytic heat of combustion sensors. As a comparison, although not currently approved for use on underground mining equipment, instruments with infrared sensors are evaluated in this study. Potential advantages of using infrared sensors include faster response time, long-term stability, and reduced maintenance needs. Tests conducted in the laboratory and at a full-scale model mine compare the performance of catalytic heat of combustion and infrared sensors operating under test conditions designed to simulate airflow conditions underground.

1 Background

Methane monitors mounted on all operating mining machines must give warning signals when methane concentrations exceed mandatory standards of 1 pct or 2 pct (30 CFR §75.342). Two types of sensors, infrared and catalytic heat of combustion, are commonly used for measuring combustible gases such as methane in non-mining applications. In underground applications, only heat of combustion sensors are used.

Infrared methanometers operate on the principle that methane gas will absorb infrared light at certain wavelengths including 1.33, 1.66, 3.3, and 7.6 microns. In the two infrared monitors tested, the light from a tungsten filament is transmitted through an enclosure containing the sampled gas. A mirror at the end of this enclosure reflects the light back to a detector. An optical absorption filter placed in front of the detector limits the infrared wavelengths to those that are primarily absorbed by gas being measured (in this case methane). The detector measures the intensity of the filtered light, which varies inversely to the concentration of the methane in the enclosure. Although other hydrocarbons such as ethane and propane will also absorb light in the absorption wavelength regions of methane, such as 3.3 microns, the optical filters should be carefully selected to minimize the interference due to higher hydrocarbons.

The catalytic heat of combustion sensor uses a very fine platinum wire contained within an alumina bead coated with a catalyst material, typically platinum or palladium. During operation, the bead is heated to a temperature sufficient to promote combustion of the methane gas with oxygen on the surface of the catalyst. The increased heat generated by the combustion increases the resistance of the wire inside the bead. The resistance change is monitored by a Wheatstone bridge circuit which generates an electrical signal proportional to the methane concentrations. A second bead in the bridge, not treated with the catalyst material, is used to compensate for temperature, pressure, and humidity changes.

All methane monitors currently used on mining machines rely on catalytic heat of combustion sensors. Although the infrared type sensor is widely available, no instrument with this type of sensor is currently approved for use on underground mining equipment. However, some equipment manufacturers are developing new instrumentation and have indicated that the infrared sensor has faster response time, longer service life, and requires less routine maintenance than the catalytic sensor. Therefore, further information comparing the performance of the two types of sensors is needed.

This research was conducted to compare the performance, including response time and accuracy, of selected instruments using infrared and catalytic sensors. Test conditions were designed to simulate gas and airflow conditions in an underground mine. Tests were conducted in an environmentally controlled box and a full-scale model of a mining entry.

2 Test Procedures

2.1 Test Instruments

Two instruments with infrared sensors and one instrument with a heat of combustion sensor were selected for these tests. The infrared instruments were designated IR-1 and IR-2 and the heat of combustion instrument was designated HC. Figure 1 shows the three sensor heads. The two infrared instruments had similar sensors. However, the environmental caps that covered the sensor heads to provide protection from dust and water were different.

2.2 Environmental Text Box

Instrument response time was measured using a specially designed test box (Taylor, Chilton, et al., 2004). The instruments were placed in the 36- x 36- x 36-cm (14- x 14- x 14-in) wooden box which was then sealed (see Figure 2). Approximately 1000 cc of methane calibration gas (99 % methane) was injected into the box using a

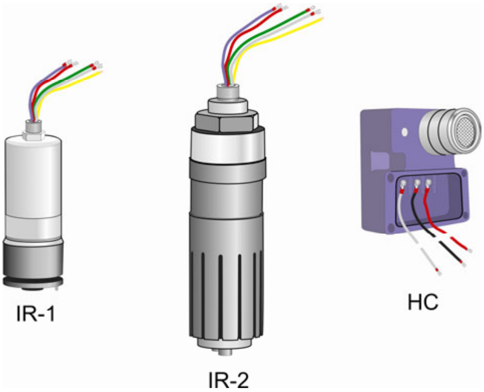

Figure 1. Test sensor heads.

plastic syringe. Injection of the gas required less than 4 seconds. Two four-inch fans attached to the bottom of the box quickly mixed the methane and air. The resulting concentration in the box was approximately 2 pct methane by volume. Although a small amount of gas leaked from the box, the methane concentration remained relatively constant (approximately 2 pct by volume) for more than 2 minutes. A computer-based data acquisition system was used to record once a second the concentrations measured by each instrument. The test was repeated once and the results averaged.

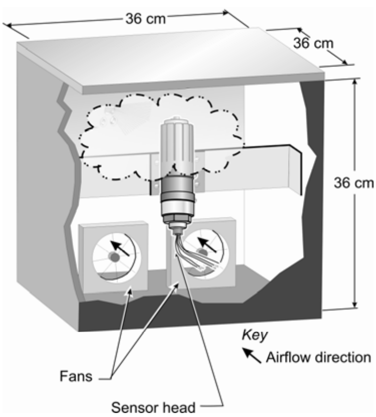

Figure 2. Environmental test box.

2.3 Ventilation Test Gallery

Tests were also conducted in the NIOSH ventilation test gallery, a full-scale test facility designed to simulate airflow in an underground mine entry. The test gallery has been described in detail in previous publications (Taylor, Timko et al., 2004). For these tests, regulator doors were used to adjust and direct intake flows behind a curtain. The 2.2-m- (7-ft) high air-intake curtain was supported by a wood frame constructed 0.6 m (2 ft) from the left side of the entry (see Figure 3). For all tests the distance from the end of the curtain to the simulated face was 10.7 m (35 ft).

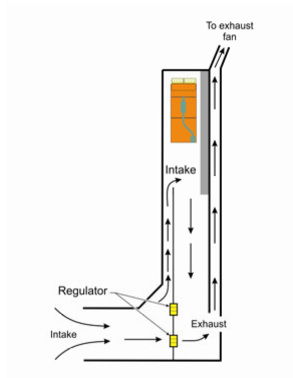

Figure 3. Ventilation test gallery.

The face area was 5 m (16 ½ ft) wide. A model mining machine was positioned near the right side of the face. The mining machine has a simulated scrubber system that includes inlet openings on each side of the machine, a fan with ducting to move the air from the inlets to the rear of the machine, and a single scrubber exhaust at the right rear of the machine (Figure 4).

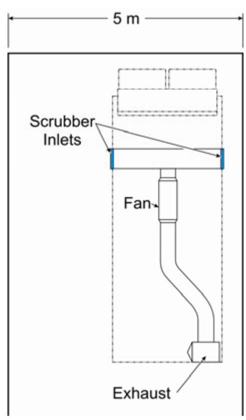

Figure 4. Model mining machine with scrubber.

Ventilation conditions in the test gallery were varied between tests by changing the scrubber and intake flow rates. Tests were run with scrubber flows of 1.9 m^3/s (4000 ft^3/min), 2.8 m^3/s (6000 ft^3/min), and with the scrubber off. Intake flow was either 1.9 m^3/s (4000 ft^3/min) or 2.8 m^3/s (6000 ft^3/min). Tests were conducted for the six different operating conditions given in Table 1.

To simulate liberation of methane from a mining face, line gas (see description below) was released from a manifold made of four 4.3-m (14-ft) long horizontal copper pipes that were located 0.1 m (4 in) away from the face.

Table 1. Ventilation gallery test conditions

Test condition	Scrubber flow (m^3/s)	Intake flow (m^3/s)
1	No scrubber	1.9
2	No scrubber	2.8
3	1.9	1.9
4	2.8	1.9
5	1.9	2.8
6	2.8	2.8

During each test a gas flow of 9.4 l/s (20.2 cfm) was set and monitored using a rotameter.

The three sampling instruments were placed on the right side of the mining machine, 2.6 m (8 ft 8 in) from the face (see Figure 5). Sensor heads were spaced approximately 5 cm (2 in) apart.

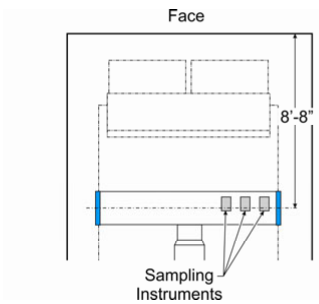

Figure 5. Sampling locations for sampling instruments.

Methane concentrations measured with each instrument were recorded each second using a computer-based data acquisition system. Each test in the gallery was 10 minutes long. During the first three minutes of each test the methane and gas were allowed to mix. Data collected during the last seven minutes of each test were used to calculate the average concentration for that test. Each test was repeated six times and the results averaged.

3 Results and Discussion

3.1 Environmental Text Box

Response time is defined as the time for the monitor to respond to the methane after it reaches the monitor sensor head. To compare the response times for the three instruments, concentrations were measured for approximately two minutes after injecting the gas into the environmental box. The response time curves (see Figure 6) were drawn by plotting the percentage response versus elapsed time. The percentage response is the concentration measured at a given sampling time divided by the average high concentration measured for that test. The 90 pct response times, shown on Figure 6, were taken directly from these curves.

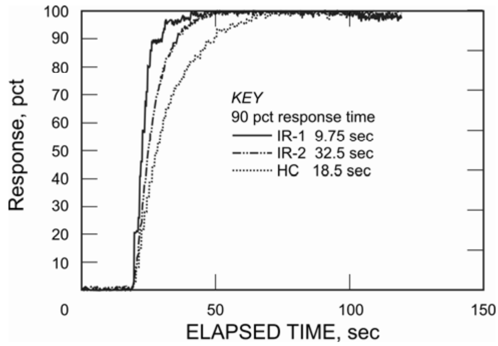

Figure 6. Response time curves for sampling instruments.

The differences between the 90 pct response times are large. At least part of the difference was believed to be due to the design of the environmental caps. Earlier tests with heat of combustion sensors showed that the flow path through the environmental cap can have a significant effect on instrument response time (Taylor, Chilton et al., 2004). Therefore, the environmental caps used with the two infrared sensors were examined further. It was noted that each of the infrared caps has narrow openings that allow passage of air through the cap (Figure 7). Only the IR-2 instrument also has a filter material (180 micron pore size) that lines inner surface of the IR-2 cap. The composition of filter is not known, but the movement of the air is clearly slowed as it moves through the material. After these observations were made, the environmental caps were removed from both infrared instruments and response time measurements were made again to determine how much the caps affected response times. With the caps removed, the 90 pct response times for both instruments were approximately 3 seconds (Figure 8).

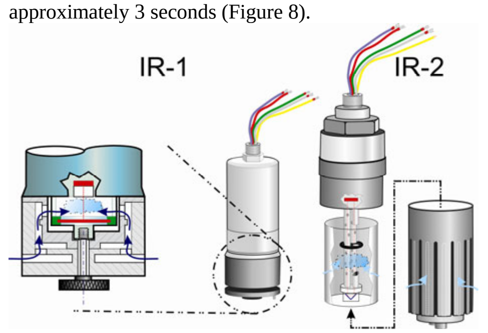

Figure 7. Environmental caps and flow paths.

One additional test was conducted in the environmental box to determine if ethane gas would affect instrument readings. Line gas containing ethane and methane is obtained from a commercial supplier and is released from the pipe manifold during tests in the ventilation test gallery. A sample of this line gas, analyzed using gas chromatography, confirmed that it contained approximately 95 pct methane, 4 pct ethane, and less than one pct higher hydrocarbons and inert gases.

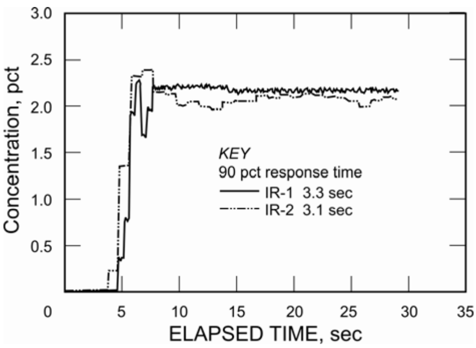

Figure 8. IR-1 and IR-2 response times with environmental caps off.

Approximately 1000 cc of line gas was injected into the box using a plastic syringe. Figure 9 shows the concentrations measured by the three instruments. The highest concentration measured by IR-1 was about 1 5 times higher than the readings obtained with IR-2 and HC. To correct for this overestimate of methane concentrations, all measurements made in the gallery with IR-1 were reduced by 1/3.

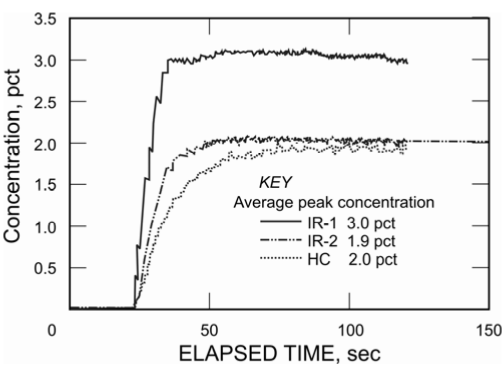

Figure 9. Average peak concentrations measured in environmental box using line gas.

3.2 Ventilation Test Gallery

The three machine-mounted test instruments were used to measure the average methane concentrations for the 6 test conditions (Table 1). The average readings were determined using the final 420 one-second readings (representing the last seven minutes) obtained for each 10-minute test. The readings varied for the different test conditions while for each individual test condition the readings for the three instruments were approximately the same (see Figure 10).

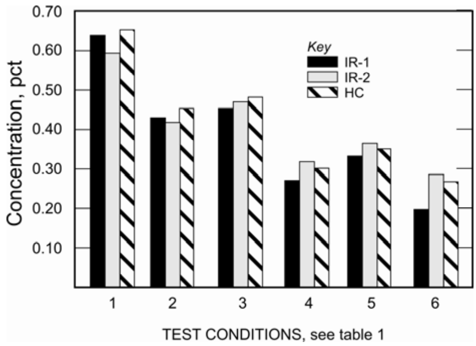

Figure 10. Average concentrations measured on the mining machine.

The 420 one-second readings obtained from each 10-minute test were plotted to show how the concentrations varied during each test (Figure 11). The data shown in Figure 11 were obtained for test condition 2 when the scrubber was off and the intake flow was 2.8 m^3/s. For this test the average concentrations for IR-1, IR-2, and HC were .37, .38, and .41 pct methane, respectively. The graph show how the measured concentrations varied for each instrument. Each of the instruments showed similar patterns of change in concentration during the test. Figure 12, expands two minutes of data taken from Figure 11. The expanded data shows how quickly the instrument readings changed in response to changes in gas concentrations.

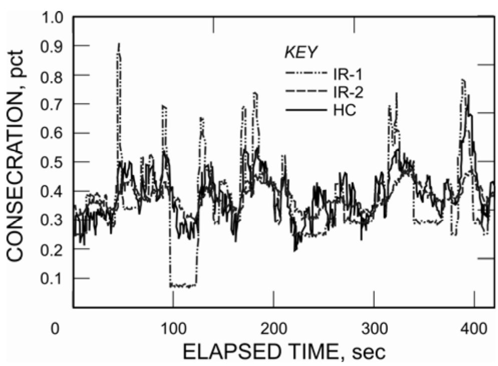

Figure 11. Variation in gas concentrations measured on the mining machine.

In general, the instrument with the fastest response time (IR-1) showed changes more quickly. Also, peak values were usually highest for the IR-1 instrument due to the faster response time.

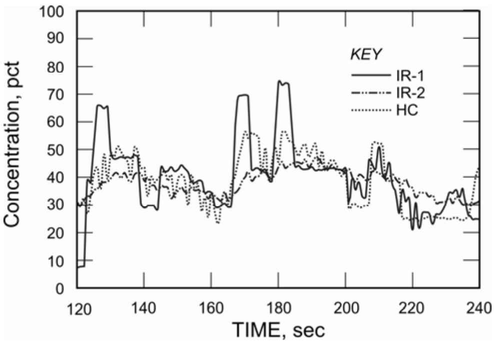

Figure 12. Variation in gas concentrations (120 to 240 seconds).

4 Conclusions

Response times for the infrared instruments were largely dependent on the construction of the environmental cap. The IR-1 response was faster than the response for HC, but the response for the IR-2 was slower than the response for the HC. The explanation for the latter was that the filter material in the environmental cap of IR-2 increased the time required for the gas to reach the sensor. However, the filter material provides better protection for the sensor from coal dust and water sprays. Underground testing is needed to determine the level of protection required to maintain the performance of the infrared sensor. Based on the current study, if protection provided to the sensor head is reduced, instrument response would be faster.

The results showed that the ethane in the line gas had a great effect on measurements made with instrument IR-1. Instrument IR-1 overestimated methane content in the line gas by 1/3. A correction was made for all readings made in the ventilation gallery with IR-1. Most gas in underground mines contains methane and ethane. If the percentage of ethane in the mine gas is not known, it is important to use either heat of combustion or infrared instruments such as IR-2 which are not affected by the presence of ethane gas.

To clarify, the filter used in the infrared instrument should, as much as possible, remove wavelengths of the transmitted light that are absorbed by ethane and higher hydrocarbons. Specifications for the filters used in IR-1 and IR-2 are not known. However, it is likely that certain wavelengths of light passing through the IR-1 sensor were absorbed by the ethane, resulting in overestimates of the methane concentration. On the other hand, the filter in IR-2 effectively removed light having wavelengths absorbed by ethane. Additional work is needed to specify requirements for filters used in infrared instruments.

As shown in Figure 10, average gas concentrations measured by all three instruments were affected by changes in intake and scrubber flow. For each test condition, the average readings of all three instruments were similar. However, the differences in response times were evident when measured concentration was plotted versus time for individual tests (Figures 11 and 12). In general, the faster the instrument response, the quicker the change in concentration, and the higher the peak values.

Peak concentrations measured at the mining face are indications of poorer mixing which usually is the result of inadequate face ventilation (Kissell et al., 1974). Therefore, the ability to monitor peaks provides information that can be used to predict the buildup of methane at the face. To demonstrate, while collecting data on the mining machine, a fast-response infrared monitor, similar to instrument IR-1, was used to measure methane levels one foot from the face. This instrument was calibrated to measure methane concentrations up to 100 pct by volume. Figure 13 shows how methane levels at this face location varied during the same time frame when Figure 12 data were collected.

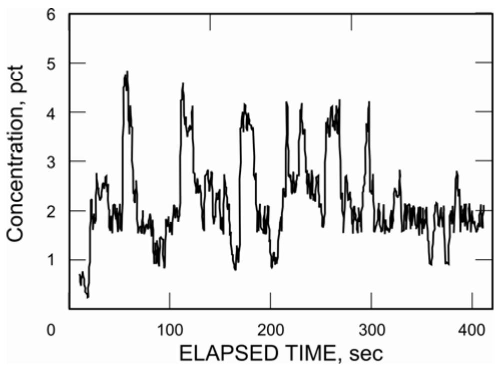

Figure 13. Variations in methane concentration one foot from the mining face.

As was expected, the average and peak concentrations were much higher at the face. However, it was not possible to correlate concentrations measured on the machine and at the face. Further studies are needed to establish whether concentrations measured on the machine (average and peak) can be used to predict face concentrations.

When looking specifically looking at the response time data, the results of this study do not clearly show advantages for using infrared sensors instead of catalytic heat of combustion sensors. Long-term testing in underground coal mines is needed to determine whether monitors with infrared sensors have better long-term stability and require less maintenance as suggested by equipment manufacturers. A critical factor for the use of infrared instruments is the type of filter required to protect the sensor head from exposure to dust and water. The potential benefit of faster response will depend on the type of filter material required for the environmental cap.

References

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