Using ultrasonic anemometers to evaluate factors affecting face ventilation effectiveness

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Abstract

A test system was developed at the National Institute for Occupational Safety and Health's ventilation test gallery for measuring airflow using a three-axis ultrasonic anemometer. The gallery was used to simulate face airflow conditions in underground mines having a blowing curtain. Airflow data, collected at multiple sampling locations between the face and the end of the curtain, were used to draw airflow profiles for different curtain setback distances, intake flow quantities and entry widths. In addition, methane was released at the face, measured at the sampling locations and displayed as methane distributions in the area between the curtain and the face. Entry geometry had a significant effect on airflow patterns, and the flow patterns affected the distribution of methane in the entry. Flow measured at and parallel to the face was a good predictor of methane dilution and removal within 0.6 m (2 ft) of the face.

Background

In coal mines the highest methane concentrations are often found near the development faces where coal is being mined. Effective face ventilation requires that methane liberated at the face be diluted and removed quickly. An important factor affecting face ventilation effectiveness is the quantity of intake air delivered to the face from the end of the face curtain or tubing. To maintain methane concentration below 1%, as required by law (30 CFR 75.323 (b)), an adequate quantity of intake air must be supplied to the face. Normally, the quantity of air reaching the working face is determined using flow readings made at the inby end of the entry's curtain or tubing (30 CFR 75.325 (a)(2)). However, past studies have shown that these calculated quantities might not be good estimates of how much air actually reaches the face (Thimons et al., 1999). Better estimates of face airflow could be made if airflow direction and speed were measured closer to the face. However, it is difficult to make more accurate measurements between the curtain and the face because airflow direction and speed constantly change in this area.

Instruments such as a rotating vane anemometer or a pitot tube and a magnehelic gauge are used to measure airflow behind the curtain or in the tubing. A vane anemometer can be used to measure flow velocity inby the tubing or curtain, but it must be aligned with the airflow to give accurate readings. Most often, smoke tubes are used to determine flow direction. Although only qualitative in nature, valuable information about face airflow patterns was obtained using smoke tubes (Luxner, 1969).

A previous paper (Taylor, 2004) describes how a test procedure was developed and used for measuring airflow direction and speed in NIOSH's ventilation test gallery using ultrasonic anemometers. This paper describes a continuation of that work. Airflow direction and speed in empty entries are measured and compared for selected curtain setback distances, entry widths and intake flow quantities. The effects of flow on face methane distributions are discussed.

Test conditions

Tests were conducted in the NIOSH Pittsburgh Research Laboratory's ventilation test gallery (Fig. 1). One side of the gallery was designed to simulate a mining entry with a 2.2-m- (7-ft-) high roof and with ribs 5 m (16.5 ft) apart. For half of the tests, the entry width was reduced to 4 m (13 ft) by building a wall 1 m (3.5 ft) from the right rib.

The exhaust fan draws approximately 5.9 m^3/s (12,500 cfm) of air through the gallery. To simulate airflow in an underground mine, air was directed toward the entry face using a 2.2-m- (7-ft-) high curtain that was supported by a wood frame constructed 0.6 m (2 ft) from the left side of the

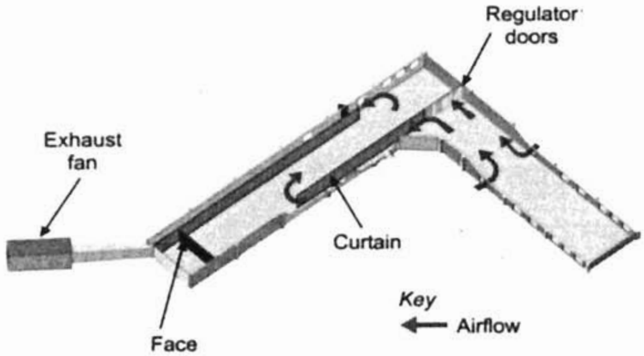

Figure 1 — Ventilation Test Gallery.

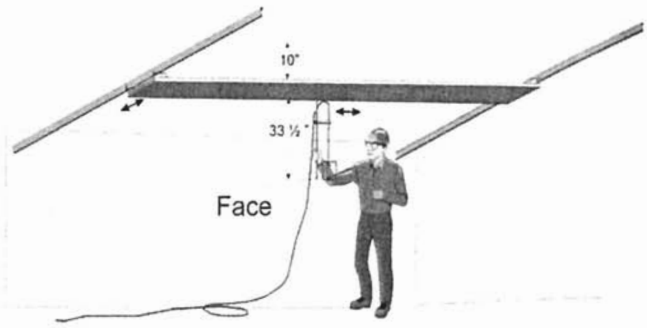

Figure 4 — Overhead support system.

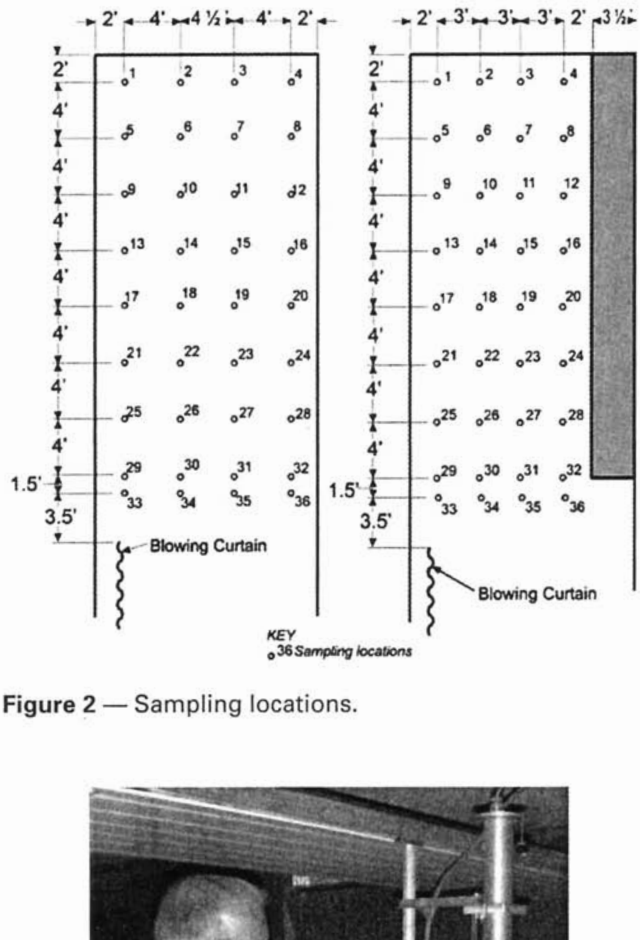

Figure 2 — Sampling locations.

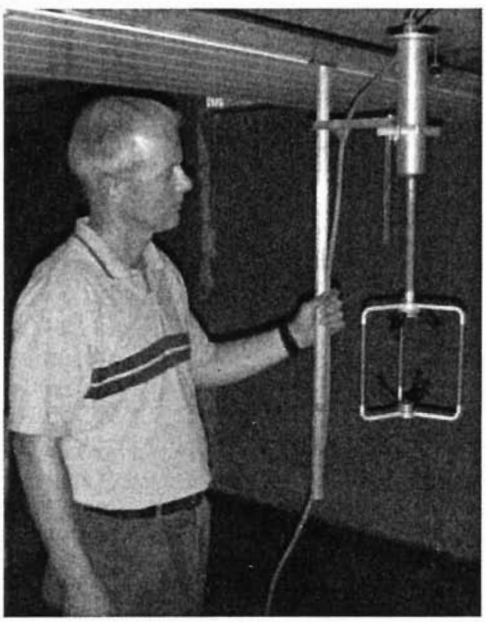
Figure 3 — Three-axis ultrasonic anemometer.

entry. The curtain was positioned so that setback distances between the curtain and the face were 10.7 m (35 ft), 7.6 m (25 ft) and 4.6 m (15 ft). Regulator doors were adjusted to provide intake flows behind the curtain of either 2.8 or 4.7 m^3/s (6,000 or 10,000 cfm). Flow velocity behind the curtain was measured with a vane anemometer held at the centerline of the curtain. Flow quantity was determined by multiplying the average velocity times the cross-sectional area behind the curtain.

Flow and methane measurements were made for two entry widths of 4 and 5 m (13 and 16.5 ft), two intake flows of 2.8 and 4.7 m^3/s (6,000 and 10,000 cfm) and three curtain setback distances of 4.6, 7.6 and 10.7 m (15, 25 and 35 ft).

Airflow and methane measurements

Methane concentrations and airflow measurements were made at the same sampling locations. The number of sampling locations between the curtain and the face varied from 36 (for the 35-ft setback tests) to 16 (for the 15-ft setback tests). The sampling locations for the 10.7-m (35-ft) setback distance and two entry widths are shown in Fig. 2.

Airflow measurements were made between the end of the curtain and the face using "Windmaster" three-axis ultrasonic anemometers (Fig. 3), manufactured by Gill Instruments Ltd., Great Britain (references to specific products does not imply endorsement by NIOSH).

The anemometer was attached to an overhead support system (Fig. 4), which was used to move the anemometer toward and away from the face and right and left across the entry. The anemometer was inverted to facilitate positioning of the sensor head 1.1 m (3.5 ft) from the floor and roof. All tests were conducted with the sensor head at this elevation.

To compare flow direction for data collected at multiple locations, the orientation of the anemometer with respect to a reference point or location had to be maintained for all measurements. The face was selected as the reference location. The anemometer was rotated around its vertical axis until an arrow, printed on top of the sensor head, was directed toward the face. Each time the anemometer was moved, the direction of the instrument with respect to the face was rechecked.

The data collected by the anemometer pass through a power communication interface (PCI) box, which powers the anemometer and resolves each flow measurement into three orthogonal components: U, V and W. For these tests, flow component data were simultaneously collected from two anemometers and stored in a personal computer using Anemvent 2003, which is a data acquisition software developed by NIOSH specifically for use with the ultrasonic anemometers. Data

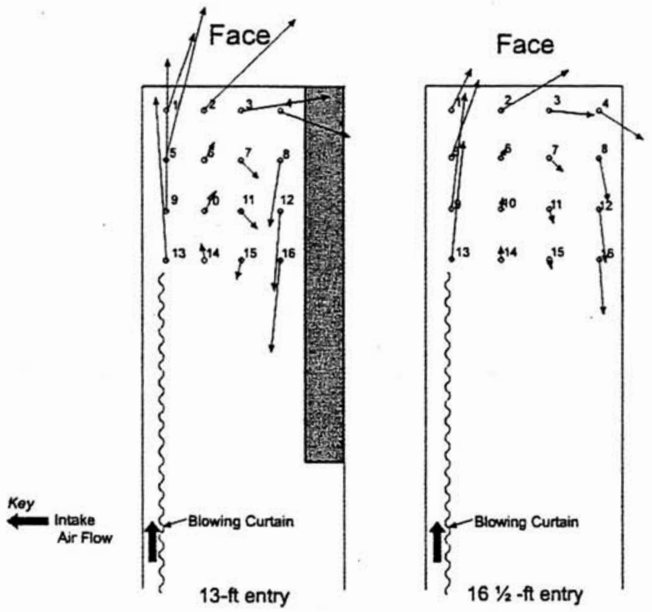

Figure 5 — Flow diagrams for 4.6-m (15-ft) setback.

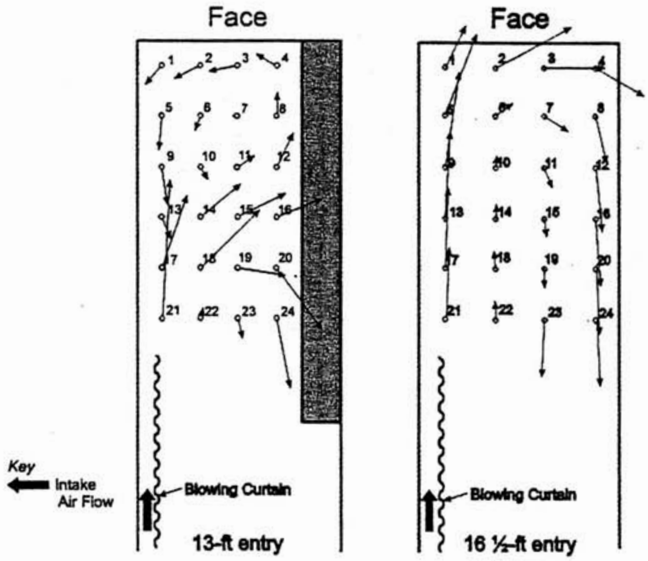

Figure 6 — Flow diagrams for 7.6-m (25-ft) setback.

from each instrument were collected at one-second intervals and the time interval between readings for the two instruments was 0.2 seconds.

During each 3-minute test, 180 sets of data points were collected. The data stored in the computer were analyzed using EXCEL functions and algorithms. The U and V components were used to calculate the flow angle and speed in the UV plane located 1.1 m (3.5 ft) from the floor and roof. EXCEL chart functions were used to draw, on a single sheet, flow vectors for all locations sampled. Each vector indicates flow direction and is proportional in length to the flow speed.

Airflow and methane measurements were made in the test gallery for the same set of operating conditions, but the measurements were made at separate times. To make methane measurements, methane gas was released into the test area through four 3-m- (10-ft-) long horizontal copper pipes that were located at the mining face. The pipes were located 100 mm (4 in.) away from the face and equally spaced horizontally to provide a relatively uniform release of gas. On the top and bottom of each of the 3-m- (10-ft-) long pipes, 1.6-mm- (1/16-in.-) diameter holes were drilled 65 mm (2.5 in.) apart. For most tests, the methane flow into the gallery was 16 L/s (34 cfm). However, during some tests (see below) the flow rate was reduced to 3.2 L/s (6.8 cfm) to prevent methane levels in the gallery from exceeding 2.5%. A rotameter was used to set gas flows at either 3.2 or 16 L/s (6.8 or 34 cfm).

While methane measurements were being made, four air-sampling tubes were suspended from the overhead support system. The hose inlets were positioned 1.1 m (3.5 ft) from the roof and floor. A vacuum pump continuously pulled air samples through each tube to one of four Bacharacch combustible gas monitors, and concentrations were measured at four locations during each test.

Methane concentrations were monitored (one reading per second) for eight minutes at each sampling location, and the individual readings were averaged. Each test condition was repeated once, and the results of the two tests were averaged. Data were stored using a commercial computer-based data acquisition system.

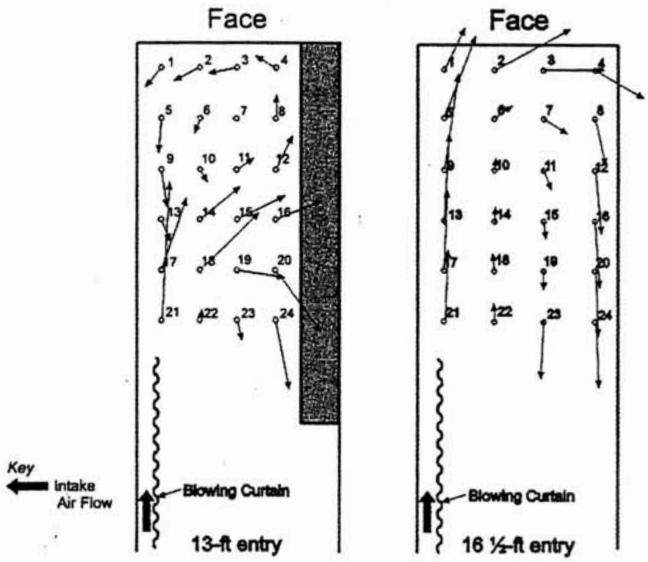

Figure 7 — Flow diagrams for 10.7-m (35-ft) setback.

Results and discussion

Airflow patterns and methane distribution. Drawings showing the flow profiles and methane concentrations in the area between the blowing curtain and the face were made for each set of the test operating conditions. Data were collected for intake flows of 2.8 and 4.7 m^3/s (6,000 and 10,000 cfm). However, to limit the material included in this paper, airflow profiles and methane concentrations are only shown for tests conducted with an intake flow of 4.7 m^3/s (10,000 cfm).

The vector drawn at each sampling location shows the direction of airflow. The length of the vector is proportional to the air speed (see Figs. 5, 6 and 7). Flow direction was similar for the 2.8 and 4.7 m^3/s (6,000 and 10,000 cfm) intake flows when the entry width and setback distances were the same. However, vectors at the same sampling locations were shorter for intake flows of 2.8 m^3/s (6,000 cfm).

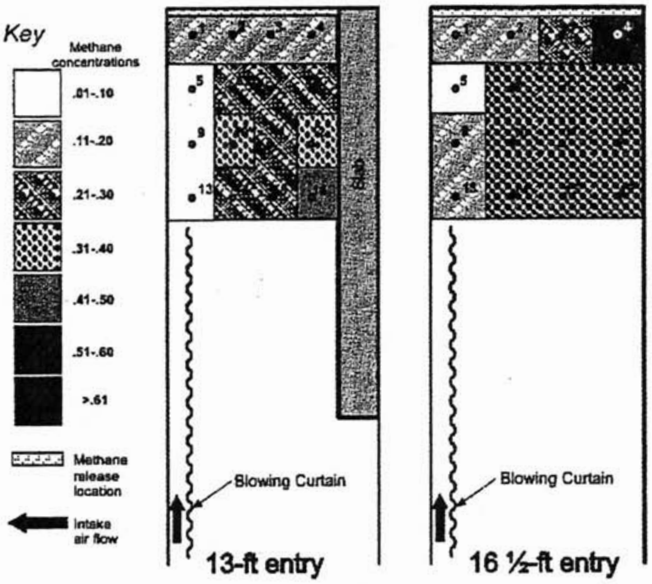

Figure 8 — Methane profile for 4.6-m (15-ft) setback, 4.7 m^3s (10,000 cfm) intake.

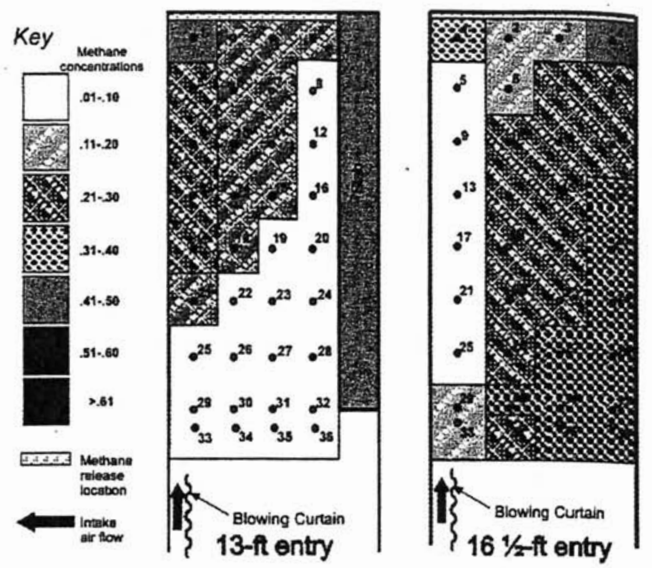

Figure 10—Methane distribution for 10.7-m (35-ft) setback, 4.7 m^3s (10,000 cfm) intake.

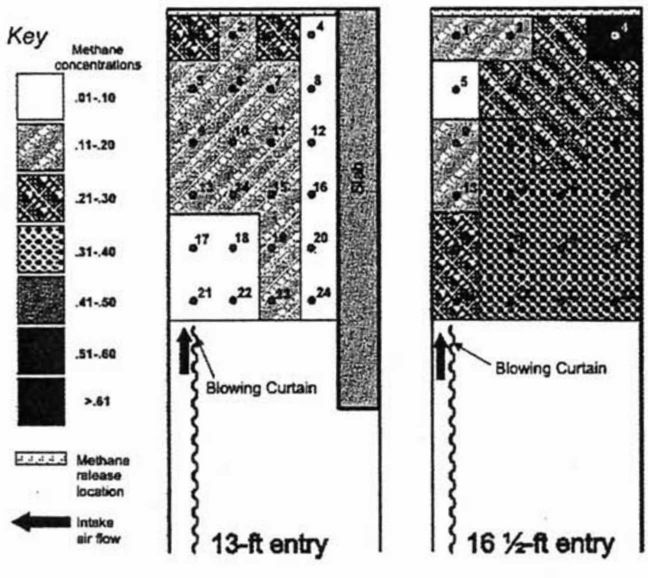

Figure 9 — Methane distribution for 7.6-m (25-ft) setback, 4.7 m^3s (10,000 cfm) intake.

The effect of entry width on flow direction was significant for 10.7- and 7.6-m (35- and 25-ft) setback distances. The airflow pattern in the 4-m (13-ft) entry was similar to a figure "8." In contrast, air in the 5-m (16.5-ft) entry moved up the curtain side of the entry to the face and returned on the opposite side of the entry. For all tests with the 4.6-m (15-ft) setback, air moved up the curtain side of the entry to the face and returned on the opposite side.

The methane profiles in Figs. 8, 9 and 10 show how methane concentrations varied between the end of the curtain and the face for tests where intake flow was 4.7 m^3s (10,000 cfm). The methane concentrations in Figs. 8, 9 and 10 were measured for the same operating conditions used for the airflow tests described above (Figs. 5, 6 and 7).

In Figs. 8, 9 and 10 the methane concentration at each sampling location is indicated by the pattern of the block that surrounds the sampling location. The distribution of methane for the 2.8 and 4.7 m^3s (6,000 and 10,000 cfm) intake tests was similar, but the concentrations measured during the 2.8 m^3/s (6,000 cfm) tests were higher. The distribution of methane between the curtain and the face in general corresponds to the airflow patterns. When air moved along the intake side of the entry to the face, more methane accumulated on the return side of the entry. When airflow moved to the return side of the entry before reaching the face, the higher methane concentrations were on the intake side of the entry.

Flow at the face. The airflow and methane profiles described above help to explain how air moves between the blowing curtain and the face. However, the most critical area for the dilution and removal of methane is within 0.6 m (2 ft) of the face. The effectiveness of a face ventilation system depends on how quickly methane is diluted and removed from this area. Therefore, data collected closest to the face (for these tests Locations 1, 2, 3 and 4) provide important information for comparing ventilation systems and evaluating factors affecting flow to the face.

The vectors shown in Figs. 5, 6 and 7 illustrate the direction of the airflow and the air speed in the direction indicated. An easier and more direct way to compare air movement at the face is to look at the magnitude of the flow as it moves parallel to the face. Specifically, one should consider the component of flow that is parallel to the face. The data collected at Locations 1, 2, 3 and 4 were used for this analysis.

The ultrasonic anemometer is designed to measure the U and V flow components in a plane that has been rotated 30° counterclockwise from the reference direction (Fig. 11).

To measure the airflow speed moving parallel to the face, the U and V axes were mathematically rotated 30° clockwise using rotation of the axes equations (Flanders, 1985). The magnitude of the rotated V flow component was then equal to the speed of the airflow moving parallel to the face.

Figures 12, 13, 14 and 15 show the speed of the airflow

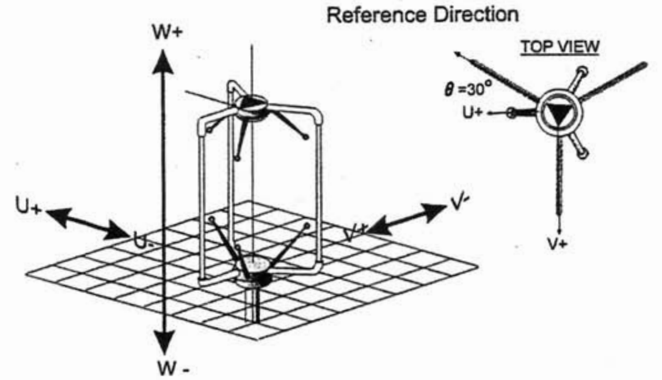

Figure 11 — Anemometer and directional components.

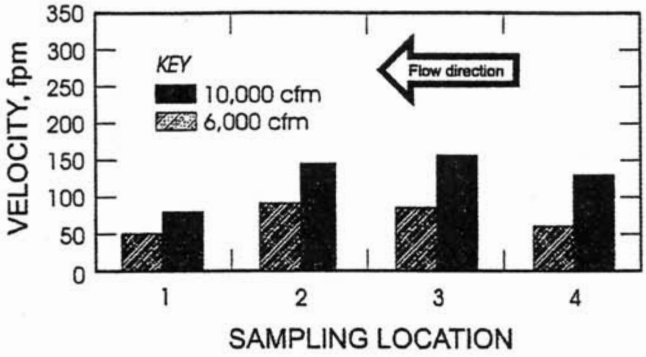

Figure 12—Airflow parallel to the face, 7.6-m (25-ft) curtain setback, 4-m- (13-ft-) wide entry.

moving parallel to the face at sampling Locations 1, 2, 3 and 4. Data are given for 7.6- and 10.7-m (25- and 35-ft) setbacks and 2.8 and 4.7 m^3/s (6,000 and 10,000 cfm) intake flows. Airflow speed was higher for the higher intake flow, regardless of direction across the face. The highest airflow speed occurred near the center of the face (Locations 2 and 3). For the same intake flows, air speed across the face was significantly lower in the 4-m- (13-ft-) wide entry. As seen earlier with the flow profiles, air moved left to right across the face in the 5-m (16.5-ft) entry and right to left across the face in the 4-m- (13-ft-) wide entry.

Figures 16, 17, 18 and 19 show the methane concentrations measured at sampling Locations 1, 2, 3 and 4 for both entry widths. Operating conditions used during these tests correspond to the operating conditions used during the airflow measurements (Figs. 12, 13, 14 and 15). Methane concentrations varied depending on the speed and direction of the air moving across the face. The higher velocities resulted in lower methane concentrations. For both entry widths the highest methane concentration was measured on the "downwind" side of the face. The highest concentrations were on the right side of the face for the 5-m (16.5-ft) entry tests and on the left side of the face for the 4-m- (13-ft) entry tests.

One cautionary note must be given when comparing data presented in Figs, 16 through 19. The methane concentrations measured during 4-m (13-ft) entry tests were lower than during the 5-m- (16.5-ft-) wide entry tests, for both the 7.6- and 10.7-m (25- and 35-ft) setback data. However, to maintain methane levels in the gallery below 2.5%, the gas flow rate through the pipe manifold had to be reduced from 16 to 3.2 L/s (34 to 6.8 cfm) during tests where the entry width was 4 m (13 ft). For all 5-m (16.5-ft) tests, the flow rate was 16 L/s (34 cfm). Direct comparisons, therefore, should not be made for ventilation effectiveness in the 4- and 5-m- (13- and 16.5-ft-) wide entries using the measured methane concentrations. However, the fact that methane levels could be maintained below 2.5% methane in the 5-m (16.5-ft) entries at the higher gas flow rates indicates that more ventilation air was reaching the face. This was confirmed by the flow measurements discussed above.

Conclusions

In some cases, the results of this study confirm earlier observations concerning face airflow, e.g., increased intake flow results in more air reaching the face. However, past studies have depended largely on methane measurements to estimate ventilation effectiveness. The quantitative data collected with the three-axis ultrasonic anemometer provides a

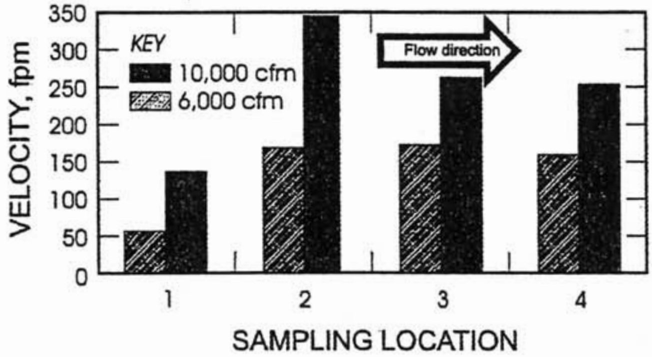

Figure 13—Airflow parallel to the face, 7.6-m (25-ft) curtain setback, 5-m- (16.5-ft-) wide entry.

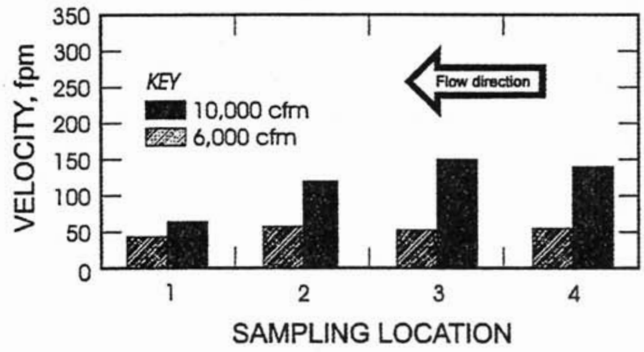

Figure 14 — Airflow parallel to the face, 10.7-m (35-ft) curtain setback, 4-m- (13-ft-) wide entry.

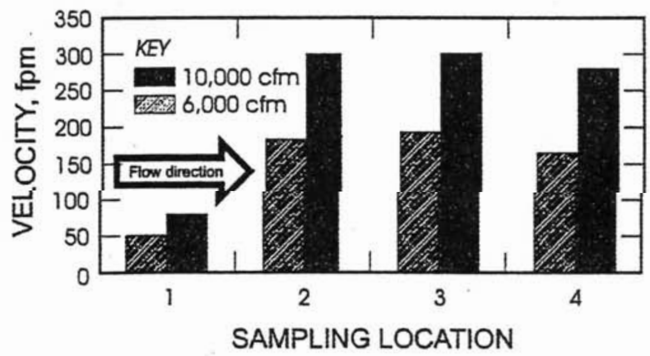

Figure 15 — Airflow parallel to the face, 10.7-m (35-ft) curtain setback, 5-m- (16.5-ft-) wide entry.

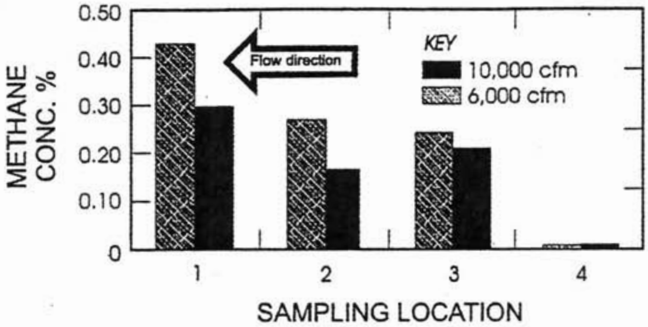

Figure 16 — Methane concentrations, 7.6-m (25-ft) curtain setback, 4-m (13-ft) entry.

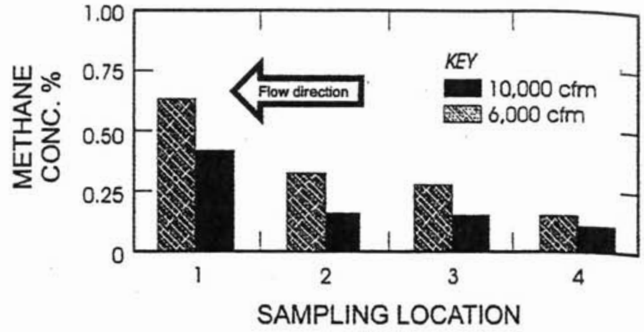

Figure 18 — Methane concentration, 10.7-m (35-ft) curtain setback, 4-m (13-ft) entry.

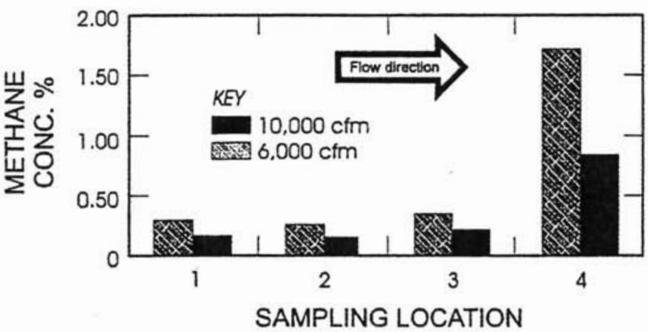

Figure 17 — Methane concentration, 7.6-m (25-ft) curtain setback, 5-m (16.5-ft) entry.

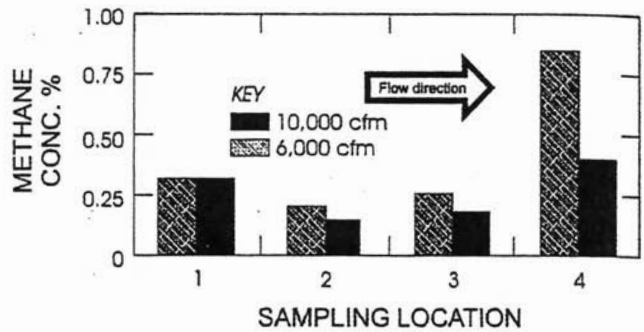

Figure 19 — Methane concentration, 10.7-m (35-ft) curtain setback, 5-m (16.5-ft) entry.

means to directly calculate ventilation effectiveness based on airflow readings. Past observations indicated that increasing the entry width should result in greater flow to the face, but the magnitude of the increase, indicated by the flow readings, was greater than expected. Thus, entry width is a factor that should be considered when evaluating the effectiveness of a face ventilation system.

Future testing will examine airflow patterns in entries containing models of mining equipment. The effects of water spray and scrubber use on flow patterns and levels of turbulence will be examined using a model of a mining machine. The effects of ventilation flow on the removal of methane liberated from holes drilled in the roof will be studied with a model roof-bolting machine located near the face.

Collecting ventilation data with the ultrasonic anemometer is relatively simple, but work in the gallery with the present test protocol is labor-intensive. For example, special care is needed to ensure proper orientation of the instrument at each sampling location. The present test matrix was based on the most efficient use of personnel and instrumentation. Sampling at more locations will improve the measurement of flow patterns. Further testing will look at improved ways to sample at more locations. The data obtained with the ultrasonic anemometers will also be used to help develop computer aided ventilation models that will supplement data obtained in the ventilation gallery.

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