Field study of longwall coal mine ventilation and bleeder performance

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Abstract

Longwall coal mine operators in the U.S. are required to ventilate multipanel longwall districts, but may have little or no knowledge about what happens to the ventilation air between the inlet evaluation points (IEPs), bleeder evaluation points (BEPs) and bleeder fans. The effectiveness of bleeder performance can directly influence the ability of a ventilation system to remove and dilute coal bed methane emissions. U.S. coal mining stakeholders have acknowledged their belief that the T-junction split at the longwall face tailgate corner is very important in controlling the distribution of ventilation air. To obtain direct measurements of bleeder performance, a tracer gas, sulfur hexafluoride (SF_6), was released into the ventilation air stream on active and inactive longwall panels. Testing was performed on multiple longwall panels that included various phases of longwall development and variable path lengths of ventilation air transport to bleeder fan installations. Changes in the T-junction ventilation air distribution over the life of a longwall panel, and its variable effect on panel ventilation airflow are discussed. These findings will assess the effectiveness of commonly applied ventilation strategies for improving air distribution and ventilation controls to meet statutory requirements.

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Key words: Longwall mining; Ventilation; Coal bed methane

Introduction

Longwall coal mines in the U.S. use bleeder systems to dilute methane concentrations where panels and gobs connect to form return ventilation airways. Many modern U.S. longwall mines use bleeder fans to remove methane-laden air from these areas inby the active longwall face. The use of bleeder ventilation networks in U.S. mines was documented by Kingery and Dornenburg (1957) as applied to room-and-pillar mines. Since that time, large-dimension longwall panels have evolved in the U.S. coal mining industry. Improvements in auxiliary methane removal systems, such as directional drilling, with the addition of ventilation-assisting technologies such as bleeder fans, have allowed mine operators to mine large-dimension longwall panels in moderately gassy to highly gassy conditions (Thakur, 2006). As a consequence, methane loading and air movement in bleeder systems have become increasingly important and complex phenomena in underground coal mines. Consequently, the movement of ventilation air through longwall bleeders will interact with many aspects of methane drainage such as gob gas ventholes (GGVs), bleeder fans and sealed district ventilation.

Statement of problem

Although longwall ventilation technology has addressed deeper and gassier coal beds, increasingly large longwall panels and larger-volume coal bed methane reservoirs remain issues of concern. A series of U.S. National Institute for Occupational Safety and Health (NIOSH) stakeholder meetings were conducted to identify problem areas to be addressed by future research in coal mine ventilation and methane control. Input from industry, regulatory agencies, labor and academia prior to research proposal development identified ventilation air transport in bleeders as a high-priority area for future investigations.

Airflows are typically measured weekly at inlet evaluation points (IEPs), bleeder evaluation points (BEPs) and bleeder fans. Unfortunately, these measurements are too infrequent to discern fluctuations in flow ranges that occur as a result of changing ventilation conditions. Even when measured flow data are available from these locations, vast expanses are present in the gob where flow rates and directions (e.g., former gateroad entries between gobs) are unmeasured and poorly defined. Other factors influencing the transport of methane-laden air in bleeder systems include rib spalling, roof-to-floor convergence and changing T-junction air distributions with increasing distance to the bleeder fan during panel retreat. The direct determination of these parameters and their influences on longwall panel airflow and transport in the bleeder ventilation network are often not possible. Also, high methane concentrations in the gob can result in increased methane emissions in the longwall returns and bleeders, which can make conforming to the 2% methane-in-air federal statutes very challenging (Mine Safety and Health Administration, 2008).

Research design and goals

To acquire data for this study, a method to quantify airflows in inaccessible areas of a longwall mine was needed. Tracer gas testing techniques have been used successfully to describe airflow movements in mine gobs, fractured overburden, around and though mine seals and air movement in face sections (Thimons and Kissell, 1974; Timko and Thimons, 1982; Timko et al., 1986; Vinson and Kissell, 1986; Schatzel

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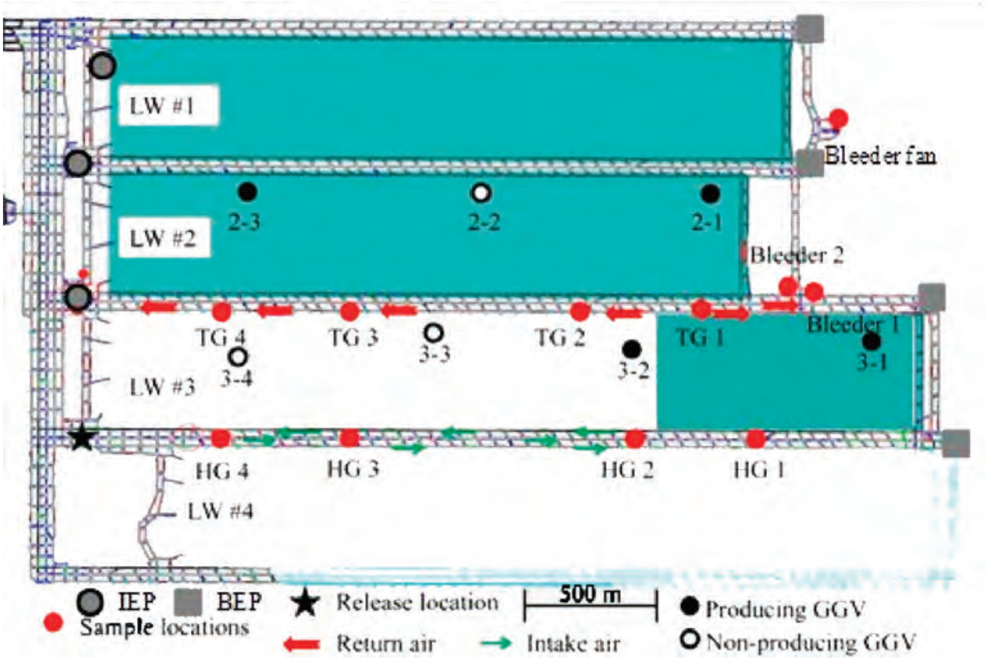

Figure 1 — Study site for tracer gas testing. Longwall configuration for test 1 is shown.

et al., 1999; Mucho et al., 2000). In addition to the tracer gas mine applications reported in the literature, the American Society of Testing Materials developed tracer gas testing standards applicable to mine voids (ASTM E 2029-99; ASTM E 741-00). The complexity of mine void space, limited access and the variable flow rates of air and gas mixtures can create substantial challenges for tracer evaluation approaches (Grot and Lagus, 1991).

This work used a series of tracer gas releases to describe airflow patterns and movements at the longwall bleeder/gob interface and to define ventilation air pathways, rates and volumes of movement at these interfaces. This work also identified the distribution of ventilation air at the longwall tailgate T-junction. A single tracer gas, sulfur hexafluoride (SF_6), was chosen to describe ventilation air movement. Tracer gas sampling was conducted underground using tube bundles attached to permissible vacuum pumps and at the surface from operating GGVs and from a bleeder fan site. This study presents ventilation parameters at early, late and completed phases of panel extraction. The tracer gas measurements were designed to be redundant with the tracer gas slug passing by multiple sampling sites underground and at the surface. An important goal of this study was to describe intake air distributions and airflow rates on active and inactive panels, including bleeder sections and transport pathways to the surface.

Description of study site

The study site was an underground coal mine operating a single longwall in southwestern Pennsylvania. The mine operates in the Pittsburgh coal bed and utilizes a three-entry gateroad system with weekly production of about 151,000 mt (166,000 t). The nearest intake air fan provides 106 m^3/s (225,000 cfm) into the section. The shaft diameter is 2.4 m (8.0 ft). The study site is located on one panel of a four-panel district (Fig. 1), where overburden depth ranged from 240 to 270 m (800 to 900 ft). A bleeder fan producing 129 m^3/s (273,000 cfm) at 3.86 kPa (15.5 in WG) at the start of the study was located adjacent to longwall panel 1 (LW#1) on a bleeder shaft with diameter of 2.4 m (8.0 ft). Airflow around the back end of the panel is separated into an outer loop (Bleeder 1) and an inner loop (Bleeder 2) on its way to the bleeder fan. Two rows of 76-cm (30-in.) pumpable cribs were installed throughout the length of the tailgate No. 3 entry, closest to the longwall block (numbered left-to-right when facing inby). This configuration was generally successful in keeping the entry open until the longwall face passed. Pumpable cribs were installed in the headgate No. 3 entry adjacent to longwall panel 4. The panel block width is 410 m (1,350 ft), entry width is 4.9 m (16 ft) and entry height is 2.6 m (8.5 ft). Each panel had at least three surface GGV sites removing gob gas via a coal bed methane-powered exhauster using a modified diesel internal combustion motor. Methane contents for the Pittsburgh Coal Bed in southwestern Pennsylvania are given in Diamond et al., 1985.

Methodology

Tracer gas was released from lecture bottles containing about 34 L (1.2 cu ft) of high-purity SF_6. An experimental protocol was developed for each tracer gas release utilizing the manual sampling of ventilation air with an underground tube bundle system. Tube bundles were 1.3 cm (0.5 in.) OD polyethylene tubing attached to SKC Inc. Aircheck vacuum pumps, which are U.S. Mine Safety and Health Administration (MSHA) permissible. The experimental protocol called for concurrent surface gas sampling to identify potential pathways of the tracer gas through the underground ventilation network and to the atmosphere. Tube bundles were installed in the panel 3 headgate No. 2 entry and the tailgate No. 3 entry, adjacent to the No. 3 panel block. Four locations for sample retrieval were chosen in the headgate and tailgate entries, as shown in Fig. 1. Filters were installed on the tubing at the inby, open ends of each sampling line. The tubing outby, open ends were covered with electrical tape until a test was performed.

Table 1 — Sample tubing lengths, volumes, and transit times.

Location	Length, m (ft)	Volume, L (cu ft)	Transit time, min
Headgate			
HG1	2,290 (7,500)	194 (6.85)	63
HG2	1,830 (6,000)	155 (5.47)	42
HG3	920 (3,000)	77.4 (2.73)	19
HG4	460 (1,500)	38.7 (1.37)	8
Tailgate			
TG1	2,100 (6,900)	178 (6.29)	55
TG2	1,650 (5,400)	139 (4.91)	42
TG3	920 (3,000)	77.4 (2.73)	22
TG4	460 (1,500)	38.7 (1.37)	9

For gas sampling, the SKC pumps were attached to the lines and gas samples were retrieved from the exhaust side of the pumps, with one pump attached to each tubing line. The length of each sampling tube is shown in Table 1. Sampling pump stations were located in the No. 3 crosscut on both the headgate and tailgate sides, just inby the submains. All gas samples were collected in 15-ml glass vials that had been previously evacuated at NIOSH's Office of Mine Safety and Health Research (OMSHR) in Pittsburgh, PA.

Transit times for the movement of samples through the polyethylene tubing were computed by determining friction factors following testing at NIOSH and during pump tests performed in the field after installation. These tubing transport times were subtracted from the tracer gas arrival times at each sampling site to determine tracer gas movements. Additional underground tracer gas sampling was conducted manually by NIOSH staff by capturing samples of ventilation air in the bottle samples. Samples were taken in this manner at the tracer gas release points and in the bleeders.

In addition to the underground sampling sites, the experimental protocol called for concurrent gas sampling at surface sites. Sampling underground and at the surface was conducted to identify potential pathways of the tracer gas through the underground ventilation network and to the atmosphere. Sampling was conducted at bleeder fan exhausts that were within the same ventilation network as the study panel. Gas sampling was also performed at GGV sites on the study panel and selected adjacent sites where borehole exhausters were actively removing gob gas. Gas samples were pumped into the glass vials by NIOSH project staff using hand-operated, high-vacuum, plastic pumps.

Samples collected during the field study were analyzed for SF6 concentrations by gas chromatography. The analytical method for this study is based on NIOSH method 6502 (1994) using a chromatograph with an electron capture detector (ECD), typically with a Ni-63 source (Fig. 2). The analytical column was a stainless steel packed column with either a Chrompak Carboplot or a molecular sieve stationary phase.

Figure 2 — In-house gas chromatographic analyses of gas samples for determination of SF_6 concentrations.

The tracer gas was injected into the ventilation airstream as short duration slugs. The movement of the tracer through the ventilation airways was anticipated to be relatively rapid, such that gas sampling could generally be completed in about one working shift. A gas chromatograph was also located at the mine site, so that gas samples could be analyzed quickly, allowing modifications to be made to gas sampling frequency and duration. Additional data collection included measurements of barometric pressure, temperature and humidity.

The exact volumes of tracer gas released during each test were computed, as were the gas volumes recovered from different sampling locations. The air distributions at key experiment locations for early, late and completed phases of longwall panel extraction were calculated. To compute retrieved tracer gas volumes at the sampling locations, plots of SF_6 concentration against time were integrated to yield the recovered volume of gas. This method has been discussed by others and is summarized in the equation below (Hartman et al., 1997):

$$Q = Q_g / (C_{av} T_t) \tag{1}$$

Where:

Q = airflow, cfm

Q_g = tracer gas quantity, cu ft

C_{av} = average concentration of tracer gas, ppb

T_t = duration of measurable tracer gas concentration sampling, min

Discussion and results

Test 1. The first of three planned tracer gas releases was a relatively large-volume release using four lecture bottles of 99.99% SF_6. The four vessels were released sequentially and continuously over a three-minute period. The volume of release was calculated to be 6.52 moles or 156 L (5.51 cu ft) at the time of release at ambient conditions. The tracer gas monitoring design for test 1 included 11 underground locations and five

Table 2 — Tracer gas statistics and airflow rates as determined or measured for test 1.

Location	Tracer gas recovered, v		Tracer gas duration, min	Average tracer concentration, ppb	Airflow	
	L	cu ft			m^3/s	cfm
HG1	nd	nd	89	366	nd	nd
HG survey site[1]					70.8	150,000
HG2	133	4.68	96	325	71.0	150,000
HG3	161	5.69	74	450	80.5	171,000
HG4	166	5.87	57	569	85.2	181,000
HG survey site[1]					89.7	190,000
TG1	nd	nd	133	247	nd	nd
TG survey site[1]					12.3	26,000
TG2	21.9	0.775	140	223	11.7	24,800
TG3	20.0	0.705	141	239	9.87	20,900
TG4	16.6	0.588	153	208	8.73	18,500
TG survey site[1]					8.73	18,500
Bleeder 1[1]	38.4	1.36	80	275	29.2	61,800
Bleeder 2[2]	16.5	0.584	100	208	13.2	28,000
Bleeder fan survey site[1]					128	273,000
Bleeder fan	80.0	2.83	452	22.9	128	273,000

nd = not determined

[1] Measured value

[2] Measured value and survey site

surface locations. In addition to the headgate and tailgate pump stations, underground tracer sampling included the tracer gas release point and bleeder locations 1 and 2 (Fig. 1). On the surface, sampling locations included GGVs 2-1, 2-3, 3-1, 3-2 and the bleeder fan. For GGV sampling, only boreholes with operational exhausters were included.

The closest sampling location to the release point was HG4, where the highest quantity of tracer gas was expected to be recovered prior to leakage to the belt entry. At this location, 165 L (5.84 cu ft) of SF_6 was measured, equaling 106% of the released gas volume. It is assumed that the error is the result of some tracer gas leakage that occurred from the lecture bottle prior to release through the regulator and from infrequent sample analysis between the peak and tail of the concentration plot (Fig. 3).

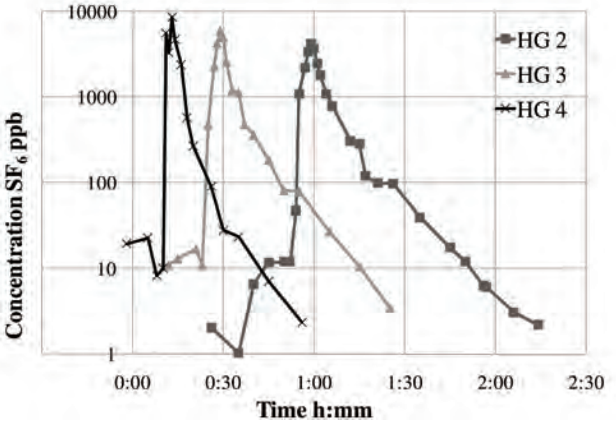

Figure 3 — Concentration and time plot for samples retrieved from headgate sampling locations outby the face, test 1.

To discern the arrival times of the tracer gas, a concentration of 10 ppb was selected as the minimum for inclusion into the tracer gas integration. The drops in tracer gas volume and maximum concentrations are distinguishable from the curves as the tracer migrates through the headgate. Between HG2 and HG1, the air splits, with some flow directed towards the bleeders and bleeder fan and with the remainder going towards the face and the belt entry. At the tailgate T-junction, the air splits again, with ventilation air either flowing inby towards the bleeder fan or outby towards the submains (Fig. 1).

Airflow measurements were made at survey sites, but airflow measurements were not made at each of the tracer gas sampling points. The expression shown as Eq. (1) assumes a conservation of mass that is satisfactory for the first sampling location after the release, but is an erroneous assumption at other headgate and tailgate locations due to leakage out of the monitored entry (Fig. 1). Leakage rates can be estimated from confined spaces using tracer gas and monitoring concentrations over time (Timko and Thimons, 1982; ASTM, 2000). Plots of leakage rates from HG4 to HG2 and from TG2 to TG4 were made using known average SF_6 concentrations. Although the graphical method did not successfully estimate magnitudes of leakage, since the monitoring sites were not confined spaces, the plots showed a linear loss of airflow in both the headgate and tailgate entries. Linear flow estimates at monitoring locations were made using the ventilation survey airflow data.

Flow rates, durations, average SF_6 concentrations and the recovered volumes of tracer gas from each sampling location

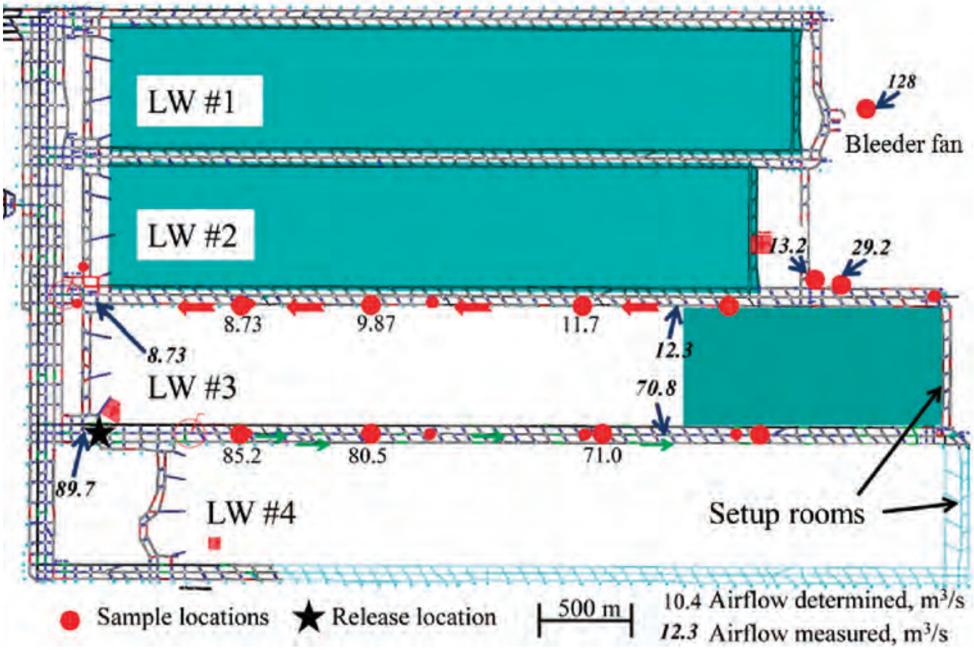

Figure 4 — Airflows measured at survey sites and determined at monitoring locations, test 1.

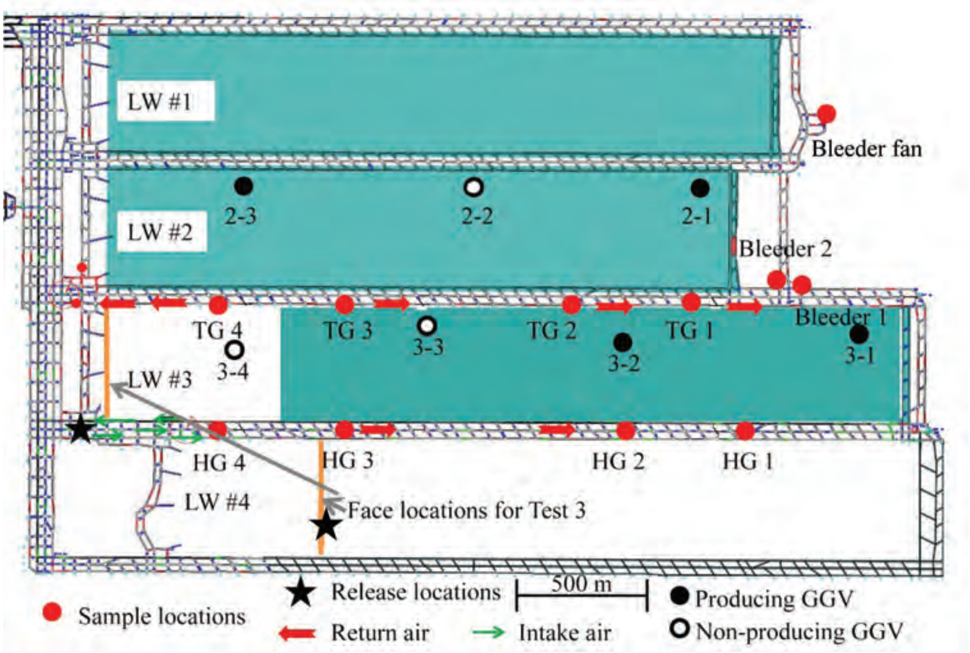

Figure 5 — Longwall panel configuration for tests 2 and 3.

are shown in Table 2. Flow data and the location of ventilation survey points are plotted on Fig. 4. Only SI units are included on the figures to make the information more legible. A consistent rate of tracer gas loss exists in the headgate and tailgate entries outby the face location, while airflow leakages change significantly inby the face. Sampling at the bleeder locations was terminated earlier than at other underground locations, due to logistical issues. Unfortunately, this schedule terminated sampling before the tracer gas tail had dropped below the detection limit, about 1 ppb, and the tracer slug characterization is less precise than for the other monitoring locations.

The only surface location that recovered SF_6 in test 1 was the bleeder fan. No tracer gas was recovered from any of the operational GGV sites on panels 2 and 3. This is significant, because it shows a lack of interaction between the mine's ventilation system and the longwall gob. Sampling at the GGVs was conducted for about seven hours during test 1 and samples were retrieved once on the morning following the release.

Tracer gas migration rates and permeabilities through the fractured gob overburden for a nearby Pittsburgh Coal bed

Table 3 — Tracer gas statistics and airflow rates as determined or measured for test 2.

Location	Tracer gas recovered, v		Tracer gas duration, min	Average tracer concentration, ppb	Airflow	
	L	cu ft			m^3/s	cfm
HG1	nd	nd	nd	nd	nd	nd
HG2	nd	nd	nd	nd	nd	nd
HG3	nd	nd	350	34.9	nd	nd
HG survey site[1]					nd	nd
HG4	65.2	2.30	80	159	85.4	181,000
HG survey site[1]					97.2	206,000
TG1	nd	nd	338	42.5	nd	nd
TG2	nd	nd	330	12.0	nd	nd
TG3	nd	nd	338	38.8	nd	nd
TG survey site[1]					9.34	19,800
TG4	4.22	0.15	78	62.3	14.4	30,600
TG survey site[1]					14.4	30,600
Bleeder 1[2]	15.6	0.55	236	45.1	24.3	51,500
Bleeder 2[2]	1.60	0.06	220	11.5	11.8	25,000
Bleeder fan survey site[1]					127	268,000
BF5	50.9	1.80	532	117	127	268,000

nd = not determined

[1] Measured value

[2] Measured value and survey site

mine have been previously reported (Mucho et al., 2000). Reports have documented tracer gas movement to the ventilation system and to the bleeder fan during a borehole release test when an adjacent GGV ceased operating. Migration rates in the fractured overburden were 0.02–0.09 m/s (5.0 to 19 ftpm) (Schatzel et al., 1999). It is possible that infrequent sampling may have contributed to the lack of detection at the GGVs during test 1. Much greater flow volumes are present in the ventilation network than are produced from the GGVs, such that low volume, short duration and accumulations of tracer gas can be expected at the GGVs, if they occur. After the gob fractured and caved, overburden near the gateroads showed apparent high migration rates and high permeabilities for movements parallel to the gateroads (Schatzel et al., 2008).

Airflow quantities at the survey sites were measured by mine personnel in the headgate and tailgate entries where tracer gas sampling was conducted. Data gathered from the tracer gas monitoring activities are shown for all sampling locations where tracer gas was recovered and where airflow data are available. The survey sites show flow measurements made in headgate and tailgate entries directly in line with test sampling locations. More air in the panel 3 intake flowed to the face and to the belt entry compared to the amount of air continuing inby in the headgate towards the bleeders. Consequently, in this early phase of longwall panel extraction, the mine operator has chosen to utilize more intake air in the face and tailgate gateroads than is used to dilute methane in the gob or in the bleeders.

Airflow on the longwall face at shield 17 was measured to be 39.5 m^3/s (83,700 cfm). About 14% or 21.9 L (0.775 cu ft) of the SF_6 was collected at TG2, suggesting that only a small portion of the airflow that was directed to the panel 3 headgate actually reached TG2. The tailgate corner can be a critical location for mine safety, where longwall face methane concentrations are generally highest and frictional ignitions can occur in certain strata.

In addition to the overall available airflow directed towards the tailgate, the distribution of gas at the T-junction is another important parameter. Although airflow was not measured at TG1 inby the longwall face, airflow measurements are available from the panel 3 longwall face at the time of test 1. Airflow on the face was 34.8 m^3/s (73,800 cfm) just before the tailgate corner at shield 186, and a flow of 12.3 m^3/s (26,000 cfm) was measured in the panel 3 tailgate just outby the face. The air quantity at the tailgate T-junction can be estimated by the difference as 22.6 m^3/s (47,800 cfm) with a distribution of 1.8:1 for inby:outby directions. Leakage of airflow to and from the gob is expected to be considerable in this region and the calculated T-junction distribution is intended to be an estimate for airflow at this location.

Another interesting feature of the test 1 data set is movement of airflow and SF_6 to the bleeders and the bleeder fan. Once the tracer gas reached the bleeder monitoring sites, 25% of the released gas was captured at Bleeder 1 and 11% at Bleeder 2, accounting for about 36% of the air that entered the panel 3 headgate.

Test 2. Tracer gas test 2 was conducted on the number 3 panel about 3.5 months after test 1, when the longwall face had advanced to the position shown in Fig. 5. With the longwall face at this position, only tube bundle sampling locations HG4 and TG4 were outby the face; all others were at inby locations. The volume of the tracer gas release was reduced for test 2 compared to test 1. The total released SF_6 volume was 2.90 moles or 68.9 L (2.43 cu ft). Surface sampling for tracer gas included the bleeder fan and active GGVs 2-1, 2-3, 3-1 and

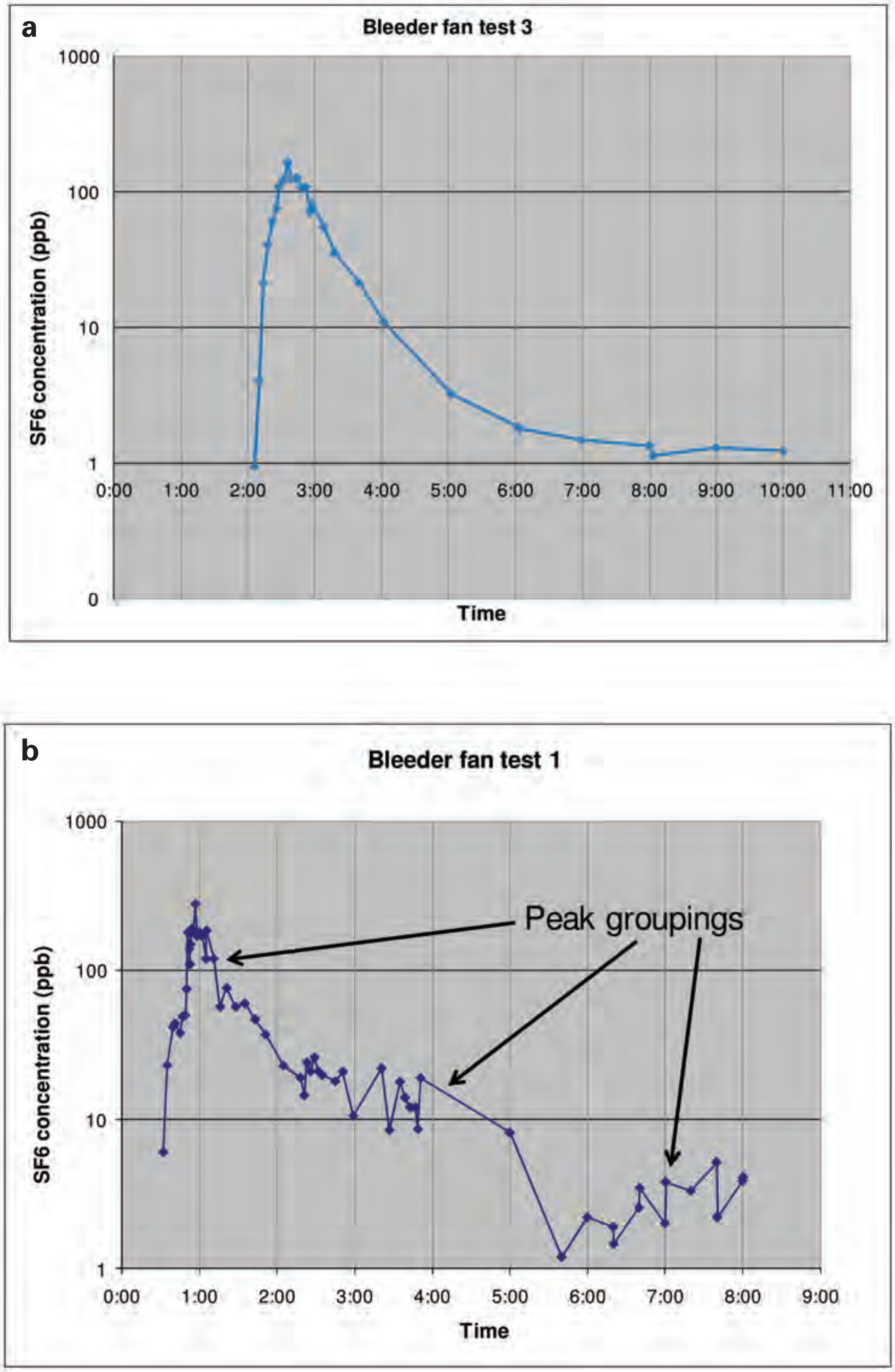

Figure 6 — Changing SF_6 concentrations over time from the bleeder fan monitoring site during tests 3 (a) and 1 (b).

3-2. The volume of tracer gas recovered at HG4 totaled 65.2 L (2.30 cu ft) for a recovery of 95% of the released gas. No gas was recovered at any of the monitored, active GGV sites.

No ventilation flow measurement was made just outby the face as in test 1 to determine leakages from intake to belt entry. Since the airflows at the mouth of the headgate were very similar in tests 1 and 2, the rates of leakage from intake to belt were assumed to be similar for this test. This yielded a flow of 85.4 m^3/s (181,000 cfm) at HG4. In the tailgate, measured data were available to produce a new plot of changing flow rates including TG4. Prior to test 2, damage to some of the sampling lines was indicated. However, the shortest lines in the headgate and tailgate gateroads used for HG3, HG4, TG3 and TG4 were shown to be intact during these pump tests, and data from these locations are included in this report (Table 3).

Despite the short distance from the mouth of the section to the face compared to test 1—about 533 m (1,750 ft) compared to 1,790 m (5,880 ft)—less intake ventilation air, 33.1 m^3/s

(70,200 cfm) was measured at shield 17 in test 2.

The fraction of tracer gas recovered at the outby tailgate sampling site TG4 was 4.22/68.9 L (0.149/2.43 cu ft), or 6% of the released gas. This value is about half of the 14% measured in test 1, suggesting that more airflow was being directed towards the bleeder to dilute methane concentrations from the more extensive longwall gob present in test 2. Airflows measured at the Bleeder 1 and 2 sites were quite similar to those measured in test 1: 29.2 m^3/s (61,800 cfm) versus 24.3 m^3/s (51,500 cfm) at Bleeder 1; 13.2 m^3/s (28,000 cfm) versus 11.8 m^3/s (25,000 cfm) at Bleeder 2 (Tables 2 and 3). The proportions of tracer gas recovered at the Bleeder 1 and 2 monitoring sites were 23% and 3%, respectively, showing a greater volume of the air being directed to the outer bleeders. However, the percentages of intake air reaching the Bleeder 1 and Bleeder 2 locations were less for test 2, despite a higher proportion of the air at the headgate corner being directed inby towards the bleeder. The tracer gas slug measured at the bleeder fan did not display multiple peaks representative of the differing flow rates and migration paths observed in test 1.

Estimates were made of the face air distribution and flows at the tailgate T-junction. Airflow quantities of 28.7 m^3/s (60,800 cfm) and 9.34 m^3/s (19,800 cfm) were measured on the face just prior to the tailgate T-junction at shield 186 and at the tailgate survey site, respectively, suggesting that the quantity of airflow inby the T-junction was about 19.3 m^3/s (41,000 cfm). This value produced an inby:outby flow distribution at the tailgate corner of about 2.1:1. This estimate is close to the previous T-junction flow distribution from test 1.

Test 3. The third tracer gas test was conducted after panel 3 had been completed and the longwall face on panel 4 had retreated to the position shown in Fig. 5. The test 3 release was 2.99 moles or 69.1 L (2.45 cu ft) of tracer gas over a three-minute period. The former headgate sample lines were now positioned on the tailgate side of the panel and were designated TG1 to TG4. None of the former tailgate gateroad sampling sites from tests 1 and 2 were included in test 3. During pretest preparations, it was noted that some of the tubing lines that had been in panel 3 tailgate number 3 entry had been compromised during mining on panels 3 and 4. Preliminary findings suggested the repair of the tubing was not successful. Consequently, the number of underground sampling locations included for analysis was reduced. The release location was modified from that used in prior tests and the tracer gas release point was relocated just inby shield 20 on the panel 4 longwall face. The bleeder monitoring locations were modified from tests 1 and 2 to include an additional bleeder sampling location to capture any tracer gas that migrated down the former gateroad between panels 2 and 3 to the inner bleeder pathway (Fig. 5). Surface monitoring locations included the bleeder fan and operational GGVs 2-1, 2-3, 3-1 and 3-2.

Due to the change in the test layout, the most desirable site to determine the amount of recovered tracer gas was at the bleeder fan. At this location, 56.6 L (2.00 cu ft) of SF_6 was captured, representing 82% of the released gas. Initially, tracer gas recovery at the bleeder fan site was thought to account for all of the released gas, suggesting that none of the gas moved out of the multipanel longwall section towards the submains and the mine operator's primary ventilation fans. A ventilation pathway out of the test study panel was later confirmed by mine management, which accounts for the relatively low quantity of recovered tracer gas.

Two ventilation parameters were of primary interest for test 3. The first was a measurement of airflow rates between longwall gobs. Although damage to the tubing lines had made direct measurements of this flow rate impossible, estimates were made. Airflows on the panel 4 longwall face measured 35.4 m^3/s (75,000 cfm) at shield 19 and 31.6 m^3/s (67,000 cfm) at shield 173 during test 3. The airflow just outby the panel 4 tailgate corner measured 15.9 m^3/s (33,600 cfm). The remainder of the airflow, about 15.7 m^3/s (33,400 cfm) was directed inby in the number 2 and 3 entries. At the panel 4 bleeder locations (corresponding to the bleeder locations from tests 1 and 2), flow rates were 5.62 and 4.25 m^3/s (11,900 and 9,000 cfm) in the outer and inner bleeders, respectively (Fig. 5). Using the estimate for the tailgate gateroad flow rate from the face towards the panel 4 bleeders, it was determined that 23.3 L (0.822 cu ft) was captured, a quantity that is somewhat higher than expected, since it accounts for about one third of the released volume of tracer gas. Air passing behind the shield line may have contributed to errors in airflow measurements at shield 173. Also, the TG3 site was not located at the T-junction corner and airflow rates certainly dropped moving inby the face such that airflow quantities at TG3 were not equivalent to airflows at the T-junction.

The final ventilation parameter reviewed for test 3 was the distribution of airflow at the panel 4 T-junction. Although the flow estimate at TG3 was high, it was likely more valid for a location nearer the longwall face T-junction. If we accept the estimate of 15.8 m^3/s (33,400 cfm) of air flowing inby from this location, then the inby:outby airflow rates were roughly 15.8 m^3/s /15.9 m^3/s (33,400 cfm/33,600 cfm) or essentially 1:1. This distribution of airflow results in far less dilution at the inby tailgate corner in test 3 than in the prior tests, a critical area for methane emission management. If the inby flow estimate is too high, the inby:outby flow would be more directed towards the submains and away from the gob.

Figure 6a shows a plot of SF_6 concentration versus time for the bleeder fan site during test 3. Essentially, a single peak was formed by the migration of tracer gas towards the bleeder fan monitoring site. Five different pathways through the gateroads and former gateroads to the bleeder fan have been identified, but they failed to produce any identifiable separate peaks. For comparison, Figure 6b shows the same methane concentration plot for test 1 when three migration pathways produced distinctive peaks on the plot. In test 1, the very different flow rates at Bleeders 1 and 2 (Table 2) produced distinct pulses of tracer gas migrating to the bleeder fan. The fastest pathway was the air split, which crossed the longwall face and then split through the Bleeder 1 and 2 locations as multiple small peaks. The next group of peaks represents the airflow, which moved inby the longwall face headgate corner, split between the set-up room and back bleeder, then split again at the Bleeder 1 and 2 locations, creating the series of peaks shown in the figure. The late-arriving, dilute group of three peaks may be related to tracer gas that moved into the gob, migrated back into the gateroad and eventually reached the bleeder fan. In test 3, the gob was much more extensive than in test 1. This increased migration distance for intake air traveling inby the longwall face, combined with the greater gob surface area, may have negated initial differences in airflow rates for the differing pathways of air movement to form a single peak of tracer gas accumulation. This interpretation implies that more extensive longwall gobs tend to modify and dilute independent ventilation air masses.

Summary and conclusions

A series of tracer gas tests were implemented in a cooperative research effort between NIOSH's Office of Mine Safety and Health Research and a southwestern Pennsylvania coal mine operator. The tests were designed to identify airflow characteristics and patterns in longwall panel ventilation networks, especially where flows affected or contributed to air movement in the bleeders. The tests evaluated three phases of longwall extraction: early panel, late panel and completed panel. Tracer gas releases were made near the mouth of the headgate into intake air when the study panel was active and on the longwall face of the next panel in the set once the study panel was completed. Tracer gas sampling was conducted at multiple headgate and tailgate locations, at the surface GGVs and at the bleeder fan. No tracer gas was recovered from any of the GGVs, although slow gas migration rates through the fractured gob and intermittent gas sampling at the surface may have contributed to this result.

Airflow computations were made at sampling locations around the panel and were reported using the results of the tracer gas tests. Tracer gas recoveries from the tests ranged from about 82% to 106% of the total released gas. The distribution of tracer gas in the bleeders accounted for 26% to 36% of the released gas distributed at these monitoring locations while the study panel was active. The lower proportion of ventilation air recovered in the bleeders was associated with the late phase of panel extraction. Air distributions were estimated at the active panel tailgate T-junctions. On the active study panel, the ratios of airflow quantities inby and outby the longwall faces were roughly 2:1 with about 9.34 to 12.3 m^3/s (19,800 to 26,000 cfm) of air flowing outby. Once the study panel was completed and the next and final panel in the set was being mined, the air distribution at the tailgate corner was roughly 1:1 inby:outby with about 15.8 m^3/s (33,400 cfm) flowing outby. Airflow patterns in the gateroads outby the longwall face and along the face did not change greatly throughout the monitored cycle of panel extraction. The loss of intake airflow inby the face and into the gob appears to greatly affect the quantity of intake ventilation air that reaches the bleeder locations. Interaction of this ventilation air with the gob is also suggested by the loss of independent air masses reaching the bleeder fan that is observed at the earlier phase of panel extraction. Controlling airflow at the T-junction is a critical safety parameter and this study suggests that the inby:outby flow distribution is not consistent throughout the monitored cycle of panel extraction. Data from this study implies that the number of longwall gobs present may be a more important influence on T-junction air distribution than the distance from the face to the bleeder fan.

The additional roof support installed in the gateroad of panel 1 is thought to have produced increased air resistance for ventilation air in test 3 compared to the prior two tests. This is the most likely cause of the change in inby:outby air distribution on the active face T-junction. The decreased proportion of ventilation air flowing inby in this scenario can be more problematic in the case of a gassy coal bed or a frictional ignition event. The 2:1 inby:outby air distribution at the tailgate T-junction that was in effect for tests 1 and 2 is the preferred ventilation design. This distribution should be effective at keeping the tailgate corner free of gob gas incursions, thereby diminishing the potential of frictional ignitions in this region.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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