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Face Ventilation on a Bleederless Longwall Panel

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Abstract

A ventilation study using tracer gas was conducted at a western US coal mine. The objective of the study was to evaluate the movement of longwall face air exchanges between the face and worked-out area and to document the presence or absence of face airflow pathways between these locations. The mine operator uses a bleederless longwall ventilation system with a back return and a blowing mine ventilation system. The study was conducted on an active panel and included both underground and surface monitoring sites. The study used sulfur hexafluoride (SF_6) released as a slug on the longwall face and in the front of the gob inby the face. The velocity of the tracer gas movement in the gob was 0.019 m/s (3.7 fpm). The rate of movement for the overall tracer gas slug averaged about 0.0091 m/s (1.8 fpm). A separate tracer gas test initiated with the release of SF_6 into the legs of the first shield showed the existence of more than one pathway of face air in the general direction from the headgate towards the tailgate corner. Maintaining adequate ventilation air on longwall faces is important for worker safety and for the dilution of methane emitted from the face and caved gob. A more detailed characterization of longwall system air and gas movement allows a mine to better assess its ventilation design for controlling gas on the face and in the gob.

Keywords

Mine ventilation; Longwall mining; Tracer gas

1. Introduction

During a series of informal stakeholder meetings run by the project team, a near unanimous concern was expressed related to the maintenance of effective ventilation airflow on longwall faces as a consequence of changing face length and caving characteristics. This study seeks to understand and improve a mine operator’s ability to monitor and control ventilation and methane concentrations across the longwall face through a range of caving characteristics and face lengths which may contribute to airflow pathways other than the primary face flow path. Additional field sites and modeling efforts are also part of this

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Conflict of Interest The authors declare that there is no conflict of interest.

research project and are used to investigate different length and caving characteristics other than those reported in this study.

National Institute for Occupational Safety and Health (NIOSH) researchers seek to identify flow paths of ventilation airflow on longwall panels with variations in roof caving characteristics and longwall face lengths. The project research aims to develop an understanding of the role of gas dynamics in variable broken rock, interactions with ventilation airflow, and methane concentrations across the longwall face area. The research also addresses continuous ventilation monitoring along the shield line to provide early detection of gas exchanges between face and gob and thus improve a mine operator's ability to monitor and control ventilation and methane concentrations around the face. In the context of this paper, the longwall gob refers to the pillared area behind the shields. This work reports on results from one project task to conduct field-based research using a tracer gas to describe face air and gob area gas movement in a bleederless longwall ventilation system that incorporated a back return.

2 Background

2.1 Site Description

This research was a collaborative effort with a mine operator to investigate effective ventilation airflow on a longwall face with an emphasis on the impacts of face length and caving characteristics and to assess the operator's ability to maintain adequate face airflow. This study site is a western US coal mine utilizing a bleederless design to ventilate its longwall panels, primarily due to the spontaneous combustion tendency of the mined coal bed.

The mine layout and study panel are shown in Fig. 1. Airflow on the headgate side is in the inby direction towards the back of the panel. Airflow is directed past the longwall face in the remaining headgate entries adjacent to the worked-out area of the active panel, which is isolated by ventilation controls constructed to the main line seal specifications. Airflow continues behind the isolated worked-out area of panel 3. Main line seals are constructed in crosscuts in the headgate and tailgate entries as shown in Fig. 2.

The study panel is ventilated as shown with intake air flowing inby in headgate entries 2 and 3, with some ventilation air continuing inby the face in headgate entry 2 as intake air. On the tailgate side of the study panel, there is a back return system where the air then flows outby in entries 1 and 2 (Fig. 2). The primary ventilation pattern around the worked-out portion of the panel is airflow inby in headgate entry 2 and continues to the portal inby the former gateroads between panels 2 and 3. Mine management discussed numerical simulations indicating the flow of gob gas outby in the vicinity of the face near the headgate side of the panel. The overburden depth over the panel ranges from about 60 to 240 m (200 to 800 ft) making the panel design supercritical in terms of rock mechanics.

Nitrogen (N_2) injection is utilized on the active longwall panels by the mine operator. The N_2 is injected into the gob of the active panel from a surface plant which produces gas of over 95% purity. This gas is pumped underground to a pipeline located in the number 2 entry in the headgate of the active panel. Additional gas lines are connected to the main line in entry 2 and extend to the crosscut seals between entry 2 and the former entry 3 which is now located in the gob at all locations inby the face. The mine operator had the capability to inject N_2 into seals at crosscuts 82 to 87, 89, 90, and 98, as shown in Fig. 1. The mine operator could also turn each injection line on or off near the seal connection. The flow of N_2 was only measured at the surface, and the average amounts injected for each day of the study are given in Table 1. Nitrogen was pumped from the surface to seals located at headgate seals on the study panel. The mine operator continued N_2 injection during the tracer gas study.

2.2 Mined Coal Bed and Local Stratigraphy

This operation is located in the Bull Mountain Basin of Montana. The mine is operating in a coal bed that is part of the Tertiary-age Fort Union Formation. The Tongue River member is part of this formation which includes the unit being mined, the Mammoth Coal bed (Fig. 3).

The Tongue River member consists primarily of buff-colored, massive sandstone, gray mudstones, and coal beds. The Mammoth Coal bed is 1.5–4.9 m (5.0–16 ft) in thickness in the Bull Mountain Basin [1]. The Mammoth Coal bed is known to split into as many as three different units in the basin, but the thickest occurrences usually do not show coal bed splits.

The rank of the Mammoth Coal bed has been measured to be between subbituminous and high volatile C (lowest rank bituminous coal), based on vitrinite reflectance $\%R_{o\ max}$ (maximum vitrinite reflectance in oil) determinations from a limited number of samples [4, 5]. This unit is a low-ash, low-sulfur coal which allows selling run-of-mine coal with no upgrading. The geologically young age of the unit and its low thermal maturity yielded a coal bed that produces no detectable levels of methane through the conventional mechanisms of gas emission and transport in the underground environment. Where overburden above the mine is low, subsidence fractures are known to occur over the mined panels. The primary access to the mine is through a slope from the surface entering the mains shown in Fig. 1.

3 Experimental Method

Sulfur hexafluoride (SF_6) tracer gas was released in two separate monitoring experiments. One test was focused on airflow on the longwall face of the active panel and the second on gas transport in the mined-out portion of the same panel. This approach allowed for the volumes of the tracer gas releases and the duration of monitoring to be optimized for each test.

The SF_6 was released in a rapid, short-term fashion (slug), and its migration through the mine was tracked by sampling at stations. The methodology for this tracer gas approach has been described in other publications by the US Bureau of Mines and NIOSH [6–8].

3.1 Tracer Gas Test Approach

The study panel is shown in Fig. 1. At the start of the study, the panel face position was between headgate crosscuts 63 and 64 (Fig. 2).

For the face experiment, the planned release of SF_6 was made within the shield legs of the first shield on the face. The monitoring consisted of drawing air samples from the face through tube bundle inlets. Air samples were taken from the face at five locations, and three more sampling locations were positioned either in the number 1 tailgate gateroad or in the back return of the tailgate ventilation (Fig. 2).

3.2 Field Measurements

The study protocol included the measurement of several parameters. Airflows were calculated by measuring face velocities and approximating the cross-sectional areas. These measurements were made at the tubing inlets on the face, locations 1–5, and in the tailgate, locations 6–8.

The protocol called for the tracer gas to be released at the start of the face of the active panel on the first day of testing. The quantity of released SF_6 was determined so that it would be carried along the face and become dilute in the face area such that within 4 h, it would be below the detection limit measured in the recovered face samples. The protocol called for the completion of the face test on the first day of testing during an extended, nonproduction work shift. The test was completed within a 12-h shift. During this period, the test was configured with face sample lines, sampling pumps, and installation of all associated equipment. Following test completion, all equipment was removed from the face area. The exceptions were sample lines 6, 7, and 8 which were installed 2 days prior to the face test and were left in place after completion of the face test.

Barometric pressure was monitored continuously at a surface site on the mine property. Underground temperature was recorded once each day of the study near the longwall face of the active panel. Air velocities were measured at each tubing inlet location on the face and at the tailgate positions with a calibrated vane anemometer. The cross-sectional area was also measured on the face for airflow rate determinations. The dimensions were measured in the field using a permissible, laser range finder. Face dimensions and airflow rates are shown in Table 2.

A second tracer gas test was configured to characterize air and gas movement associated with the gob. The gob test protocol specified a release of SF_6 about ten breaks inby the active panel face. The released volume of SF_6 was set to be at optimal concentrations if completely mixed with the anticipated void space in the gob after being released as a slug.

The gob test also included monitoring stations around the gob of the active panel. These monitoring stations included six headgate seals at the crosscuts between entries 2 and 3. These seals are designed to the 340-kPa (50-psi) US standard which also featured sampling lines installed by the mine during construction. Two researchers moved though the headgate during the monitoring period to retrieve samples from these locations.

3.3 Sampling

Gas sampling was done through collection of bottle samples. This is the sampling collection method that has been reported in previous studies [8–10]. Samples for the face test were acquired using polyethylene tubing (13 mm OD, 0.5 in OD) extending from the inlet location to the sampling station in the panel headgate (Fig. 2). The tubing inlets were positioned on the long axis of the shield centerlines of shields 9, 47, 93, 139, and 177. These inlet positions correspond to face locations of about 19.05 m, 95.25 m, 190.5 m, 285.8 m, and 362.1 m (62.50 ft, 312.5 ft, 625.0 ft, 937.5 ft, and 1188 ft) (Fig. 2). There were 186 shields on the face totaling 81 m (1250 ft) in length.

The tubing inlets were positioned over the walkway and panline, directly beneath the longwall shield canopy. The sampling lines extended from the sample line inlet to the headgate crosscut between entries 1 and 2. Sample lines 6–8 were sampled from a location outby the face in the tailgate. For the face test, the sample pumps ran continuously at rate of between 4.0 and 5.0 L/min (0.14 to 0.18 cfm) (Table 3). The initial sampling rate was two per minute on each of the face test tubing lines. Sampling becomes less frequent for the duration of the test to one sample every 10 min for the last 30 min. The overall duration of monitoring for the face test was 3 h. The gob test ran for 4 days, one shift per day.

For the gob test, samples were retrieved from seals at crosscuts 65, 70, 75, 87, 92, and 97 (Fig. 1). Monitoring locations included positions used in the face test. These were the tailgate locations 6, 7, and 8. Monitoring also included locations on the face at shields 93 and 177 which were taken manually above the face walkway, just under the canopy. Additional monitoring was conducted from a surface borehole that was exhausting a small quantity of mine atmosphere under natural flow conditions from a restricted fitting of about 9.53 mm (0.375 in.). The borehole collar was positioned inby the setup room of the study panel tailgate gateroads (Fig. 1).

3.4 Gas Analysis

The concentration of SF_6 in the sampled air was determined using a gas chromatograph (GC). Samples were drawn from the bottle samples and analyzed using a modification of NIOSH Method 6602 [11] by a Shimadzu GC8 with an electron capture detector. The GC configuration was discussed previously [8]. The limit of detection for the GC method is about 1 ppb SF_6 in air.

4 Results

4.1 Face Test Results

The tracer gas test experiment on the mine face began with the shearer positioned at the panel headgate. This was a very short duration release, approximately 2 s. Sampling was initiated at the time of the release from all face monitoring locations. The released volume of SF_6 was 2.15 L (0.0761 ft^3), determined by the weight measurements and corrected for underground temperature and pressure conditions.

\Figure 4 shows data from samples taken from face sampling lines 1 to 4. The x-axis shows test duration in minutes. Data are corrected for transport time through the sample lines (see Table 3). The plot shows that the first show (arrival) of tracer gas occurs at sample line 2, approximately 3 min ahead of the arrival on sample line 1, and the first peak (movement of released slug) also appears first at sample line 2. The second, third, and fourth arrivals are found from samples retrieved from sample lines 1, 3, and 4, respectively. The maximum SF_6 peaks occurred in the same order as the arrivals on these three sample lines, i.e., 1, 3, and 4.

Figure 5 shows more tracer gas data from the face test. Sample line 5 was located at shield 177, at about 95% of the overall face length, towards the tailgate. Sample line 6 was located inby the face in the former number 1 tailgate gateroad. Arrivals and peaks were determined on line 6 before sample line 5 meaning that the tracer gas arrived (5 min vs. 13 min from tracer release) and peaked (8 min vs. 18 min from tracer release) in the active panel gob, just inby the face before reaching the shield 177 in face ventilation airflow. The transport from the release location at shield 1 is apparently more rapid to the former gateroad inby the face at sample line 6 than the transport from the release location to the shield 177 location. There was a hiatus in the transport of the tracer gas to sample line 6 between 11 and 50 min of test duration (Fig. 5). It is not clear what produced this interruption in SF_6 flow to this location.

Data from sampling lines 7 and 8 during the face tracer gas test are shown in Fig. 6. Arrivals of the tracer gas on sample lines 7 and 8 were simultaneous at 9 min after the start of the test. The concentrations measured for these arrivals were also identical. The determined concentrations for sample line 8 were intermittent and the arrival of SF_6 also represented the peak. Only four values above detection were found on sample line 8. There were consistent measurements of SF_6 above the detection limit, between 2 and 3 ppb until 1:50 after the release. At sample line 7, tracer gas may come from the face or the gob transport which reached the study panel tailgate number 1 gateroad. In addition to the rapid transport zone described at the front of the gob, as described associated with the prior figure, there are slower pathways of movement that have been recognized in the gob, away from rubble behind the face (see following sections on gob test results and discussion for more information). Sample line 8 may also sample gas from face or gob, but the tracer gas has other possible pathways of movement other than reaching this location. To achieve the slower rate of movement to sample line 7, the tracer gas sampled at this location could not have been moving within the main face airflow for this duration. Data from sample line 5 in the previous figure suggests similar behavior of transport in the slower transport region of the gob (Fig. 5).

4.2 Gob Test Results

After the face test experiment was completed, the gob experiment was initiated. The SF_6 was released through a mine seal at headgate crosscut 73 between entries 2 and 3. NIOSH monitoring of the gob test continued for the rest of the day shift following the release and for the next four daylight shifts, one per day. The operator was mining on the evening 12-h shifts following NIOSH monitoring periods. The tracer gas release in the gob was designed to be much larger than the face release so that the anticipated SF_6 concentration in gob void space was at a good experimental concentration for detection and measurement. Typically, the target value is in the range of 100 to 350 ppb; however, in very low flow regions of gobs, much higher values can occur until diffusion and transport lower the concentration into the target range. Although high concentrations at the beginning of monitoring are not desirable, relatively large volumes of tracer gas are required for detection in longwall gobs where a smaller release volume can produce ambiguous experimental results.

The gob test included the release of four lecture bottles of SF_6 through one of the seal sampling ports. The lecture bottles were released sequentially, one after another until all bottles were used. Using the same techniques to determine the released volume of SF_6 that were previously described, the released volume was 160 L (5.7 ft^3).

After the release of SF_6 was completed at seal 73, 3 m^3 (100 ft^3) of compressed gas was injected into the seal to clear the sampling port and sample line of SF_6 and mix the tracer in the gob. The tracer gas release and the injection of compressed gas were completed within 30 min after the initiation of the gob test. Following the release, sampling commenced at all monitoring locations, at both underground and surface sites.

Figure 7 shows monitoring data from monitoring locations at seals 65, 70, and 75. From the release location at seal 73, the seal 65 and 70 monitoring locations are outby on the headgate return and the seal 75 location is positioned inby (Fig. 7). Within 30 min of the release completion, 14 ppb of SF_6 was measured at seal 75. The peak concentration measured at this location of 3200 ppb was measured at 15:00 on the day of the release (3 h after injection). Although this concentration is typically above the test design parameters, mixing in the largely sealed gob of the active panel produces low transport rates and makes mixing less dynamic and efficient than in a mine airway. These data show primary movement of the tracer gas slug to be inby from the release location. At the seal 70 monitoring location, a concentration of 362 ppb SF_6 was measured at this location on the day of the release at 15:30 (3.5 h after release). The slower transport time and decreased concentration at seal 70 versus 75 are behaviors that were thought to be related to the spread and dispersion of the tracer gas slug in the gob. Note that the research staff performed one shift of monitoring per day, on daylight shift, so there is a regularly occurring hiatus in monitoring on each day of the gob test.

On day 2 of the gob test, monitoring continued at seals 65, 70, and 75 on the headgate of the study panel. The SF_6 concentrations showed a large drop from the prior day of the study, suggesting continued gas movement in the inby direction within the active panel gob. Data from seals 65 and 70 show detectable concentrations of tracer gas (Fig. 7). Although SF_6 concentrations from seal 70 do not exceed about 2.1 ppb, data from seal 65 are as high as 36 ppb. These data are thought to represent the movement of a portion of the SF_6 slug towards the mine face within the active panel gob. On test days 3 and 4, measurable levels of SF_6 were found only at seal 75 for this group of seals, with the exception of one sample of 2.2 ppb from seal 70 on day 3.

Data from the inby set of seal locations 87, 92, and 97 are shown in Fig. 8. No SF_6 arrivals were detected on the first day of testing from seals 87, 92, and 97 along the active panel headgate.

On day 2 of the gob test, tracer gas was detected at sampling sites 87, 92, and 97. The arrival of tracer gas occurred at all three of these inby sites on day 2 with decreasing concentrations of 560, 166, and 13 ppb, respectively (Fig. 8). The peak concentration of 900 ppb at seal 87 was measured on day 2 at about 12:00 (24.5 h after release). Peak concentrations of 521 and 454 ppb were measured at the seal 92 and 97 monitoring locations on day 3. On day 4 of the study, SF_6 was still measured at all three inby sites. Concentrations of tracer gas were higher at the more inby locations on day 4, consistent with gob transport towards the back of the panel.

The arrival of SF_6 at the surface borehole occurred on day 2 of the gob test (22.5 h after release) with a maximum concentration of 2.8 ppb on that day (Fig. 9). Increasing concentrations were measured from this site on days 3 and 4 with a maximum SF_6 concentration of 115 ppb at 15:00 of day 4. The study ended before a peak concentration was reached at the borehole monitoring site.

Sampling at the longwall face was conducted during the gob test. No samples were retrieved, indicating SF_6 concentrations above the detection limit. It appears that no tracer gas migrated from the seal 73 release location on the headgate to the longwall face or into the tailgate airflow.

5 Discussion

The face test indicates that transport of ventilation air from the headgate towards the tailgate occurs both in the main face airflow and more prevalently in movement within the shield legs and possibly at the front of the gob. With only five sampling points along the 381-m (1250 ft) face, it is difficult to specifically identify each face transport pathway from the field data. Rapid transport from the release point at the first shield to the tailgate gateroad near sample line 6 was noted although the configuration of the airflow pathway is not well defined. However, this does indicate tracer gas transport through the gob during the face test. Monitoring on the active face also indicates that SF_6 persisted on the longwall face for 2:15 following the release into the legs of shield 1 which may indicate residence time within a portion of the gob. Also, there appears to be a constant SF_6 concentration on sample lines 3 and 4, suggesting limited exchanges with the gob through this portion of the face. Complete caving was noted at the field site up to the back of the shields. Data from other field sites and modeling research indicated the completely caved material formed a high permeability zone for air and gas transport despite the lack of void space behind the shields.

Gob test results suggest rates of movement of the tracer gas on the headgate side of the gob. Gas transport from seal 73 to seal 97 indicates an average velocity of 0.019 m/s (3.7 fpm). Although the tracer gas arrived at all three inby monitoring sites on day 2 of the test, the low concentration determined for the seal 97 samples is considered most representative of typical tracer gas arrivals (higher SF_6 concentration arrivals indicate the time when the tracer gas arrival was missed). Low concentration arrivals are considered to be better indicators for the measurement of velocity. However, in long duration testing that does not include 24-h monitoring, it may not be possible to always acquire samples of these lowest amplitude arrivals. This compares with 0.005–0.02 m/s (1–3 fpm) values determined for transport in mined-out panels with operating gob gas ventholes (GGVs) in the Northern Appalachian Basin [12, 13]. Transport is expected to be more rapid near the margins of the gob where permeability is greater [14]. Permeabilities are lowest towards the center of a mined-out, compacted gob. This has been especially true in cases of supercritical longwall panels.

The gob tracer gas test did document the slight movement of tracer gas towards the active panel face from a location about 670 m (2200 ft) inby the face near the headgate gateroad. This behavior was observed despite the predominant pattern of tracer gas moving towards the back of the panel (Fig. 7). Movement of gob gas towards the face on an active panel was shown in a modeling evaluation based on input data from in-mine studies [15].

Continuously recorded data were supplied by the mine operator for barometric pressure over the duration of the study (Fig. 10). Diurnal pressure cycles have been measured at some mine sites [10, 16]. These repetitive pressure changes can be important for underground coal mines with sealed areas since they can affect the ingassing or outgassing along the seal lines. Ingassing of ventilation air into sealed gob areas could be a safety hazard for spontaneous combustion in some coals, and outgassing could introduce gob gases into mine workings. Seal leakage does occur and small quantities of gob gas, ventilation air, or tracer gas can cross seal lines. However, no barometric pressure cyclicity was noted in the data set from this study site which indicates there was not a predictable daily cycle of pressure changes acting on the seal line during these tests.

Data from the injection of N_2 into the headgate seals are shown in Table 1. The N_2 added to the gob is used as an inerting agent to diminish the likelihood of spontaneous combustion. The addition of this gas might influence gas migration pathways of gob gas. The operator-supplied data provides averaged flow data before the distribution of gas underground. It is not clear how gob gas transport may have influenced the monitoring data due to the presence of N_2 added to the gob.

6 Summary and Conclusions

A tracer gas study using SF_6 was conducted at a western, bleederless longwall mine to investigate the potential for airflow losses of ventilation air off longwall faces. Additional ventilation pathways of movement were to be characterized, and any involvement with the front of the active panel gob was also a subject of this research. The overall pattern of transport in the gob was considered to be relevant to this topic and therefore was also addressed by this research.

From a release of the tracer gas within the legs of the first shield on a 381-m (1250 ft) longwall face, the tracer gas arrived and peaked at shield 47 before shield 9 with time differentials of 4 and 2 min, respectively. With continued monitoring and air movement on the longwall face, the tracer gas arrived in order of the distance traveled for the remaining three monitoring points on the face. Three monitoring locations near the tailgate corner of the face showed that the tracer gas arrived in 5 min at the inby location of the former entry 1 gateroad, behind the face. The data indicates that transport of ventilation air from the headgate towards the tailgate occurs both in the main face airflow, in movement within the region of the shield legs, and in movement through the gob.

A tracer gas test conducted in the active panel gob depicted rates and directions of transport. From a release location about 670 m (2200 ft) inby the face on the headgate side of the panel, transport of the SF_6 was primarily in the inby direction, towards the back of the panel. An outlet to the surface via a shaft does exist in the back of the multi-panel sealed area. Velocities for tracer gas movement paralleling the headgate gateroads in the gob were about 0.019 m/s (3.7 fpm). The movement of the overall slug of SF_6 depicted by the peak concentrations averaged about 0.0091 m/s (1.8 fpm). Transport of a portion of tracer gas in the gob towards the active face was observed. Maintaining adequate ventilation air on longwall faces is important for worker safety and for the dilution of methane emitted from the face. Tracer gas technology allows for the evaluation of air and gas transport in inaccessible regions of a mine. Quantitative assessments of mine ventilation in longwall operations allows an operator to have better design parameters for controlling gas on the face and in the gob.

Acknowledgments

Disclaimer The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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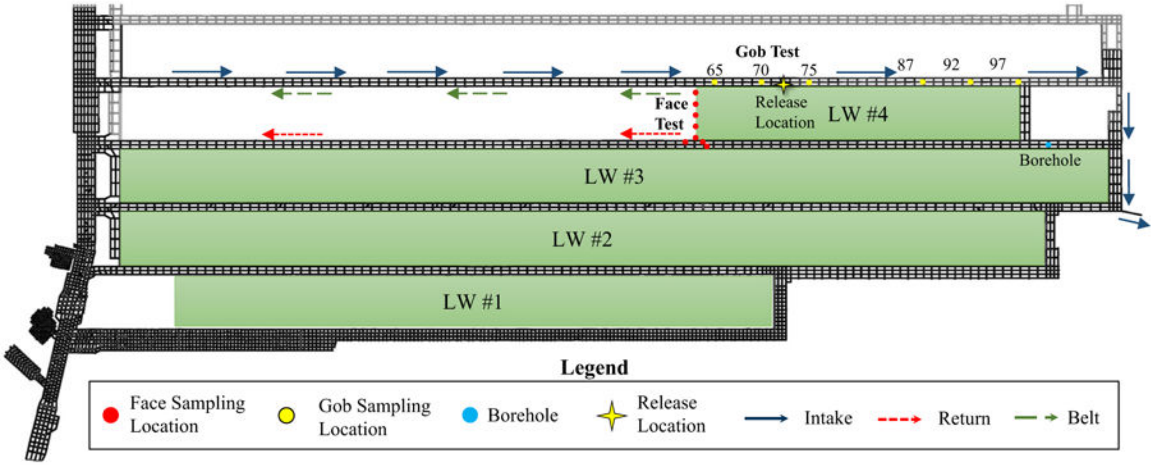

Fig. 1.

Mine study site. Study panel is panel 4. Green color indicates mined-out portions of longwall panel blocks

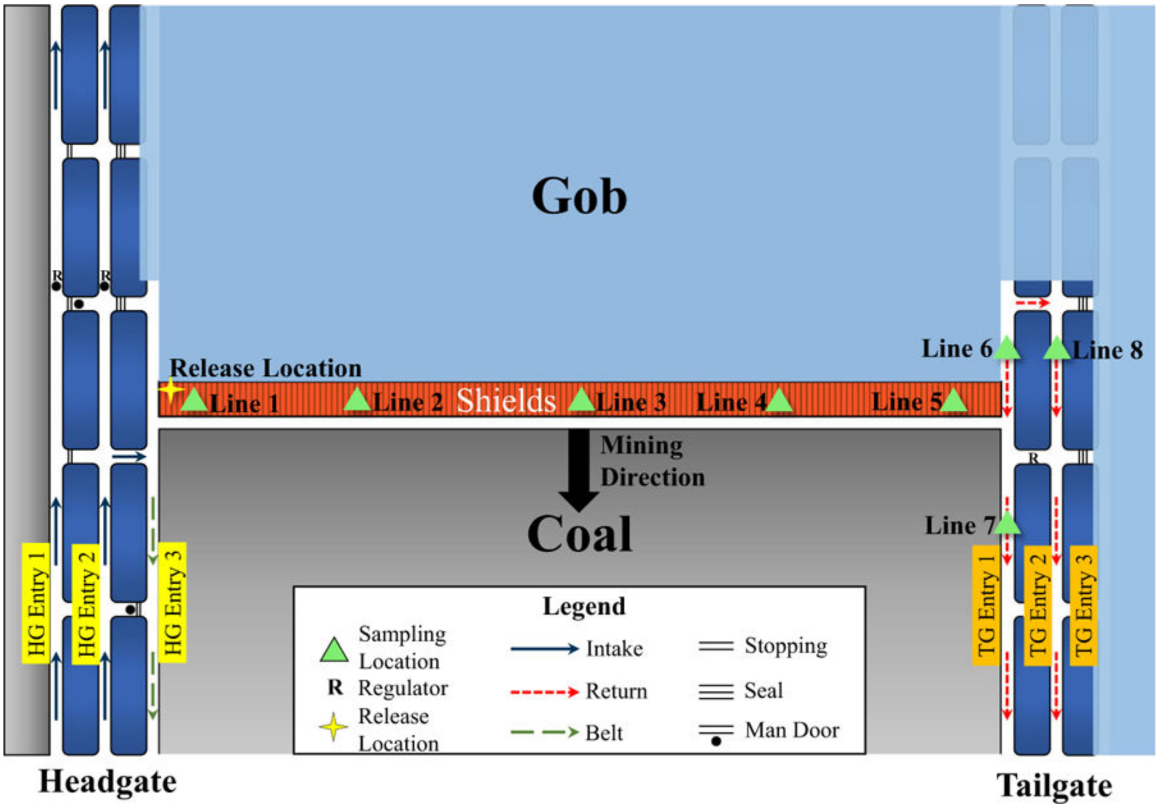

Fig. 2.

Study site. Near-face ventilation configuration and sampling locations

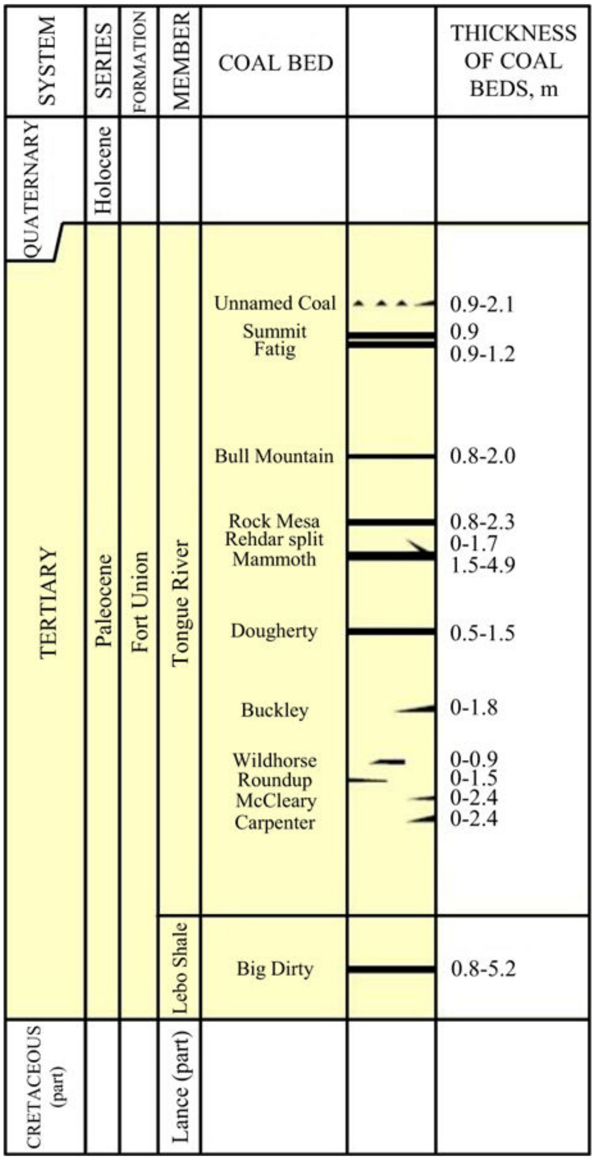

Fig. 3.

Local stratigraphy and coal beds, Bull Mountain Basin Mt, Fort Union Formation. Mine operator is working in Mammoth Coal bed. Modified from Stricker, Woolsey, Connor, and Biewick [1–3]

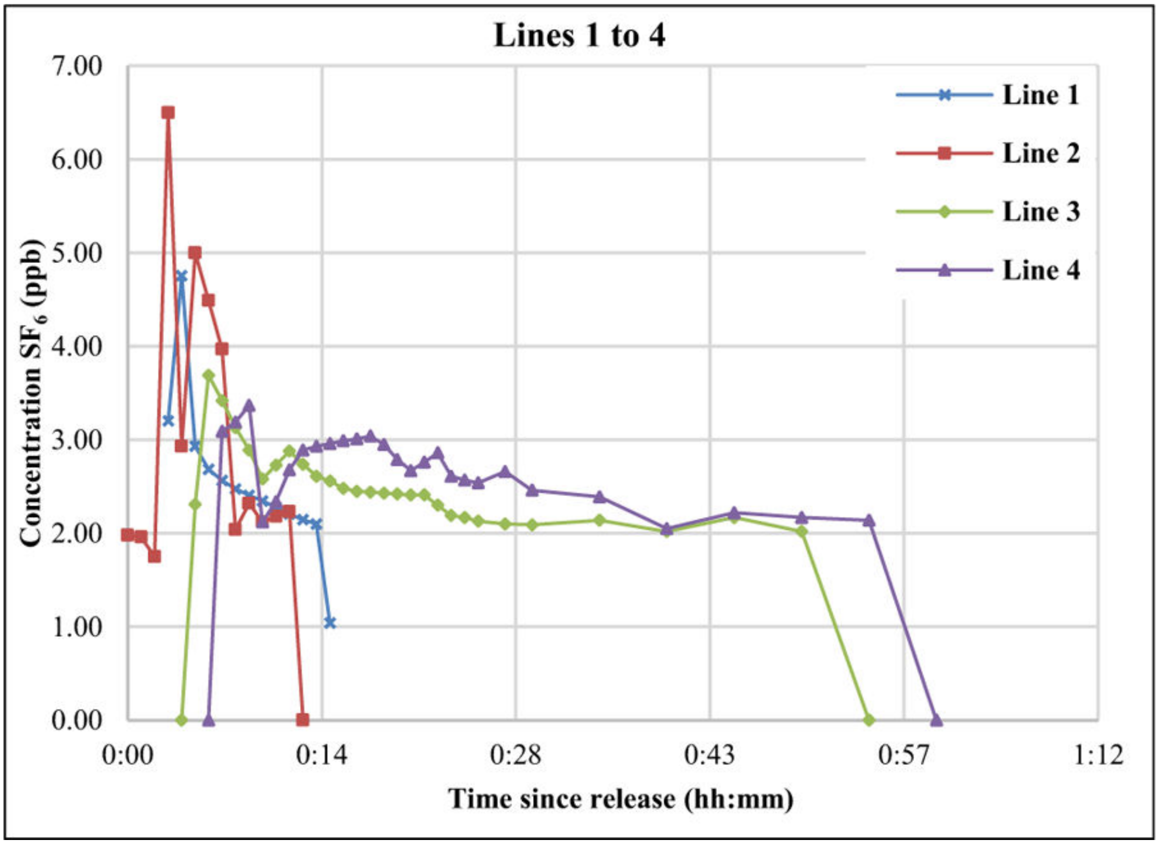

Fig. 4.

Tracer gas concentrations determined for sampling during face test over test duration, sample lines 1 through 4. First arrival and peak occurred on line 2, prior to arrival and peak on sample line 1

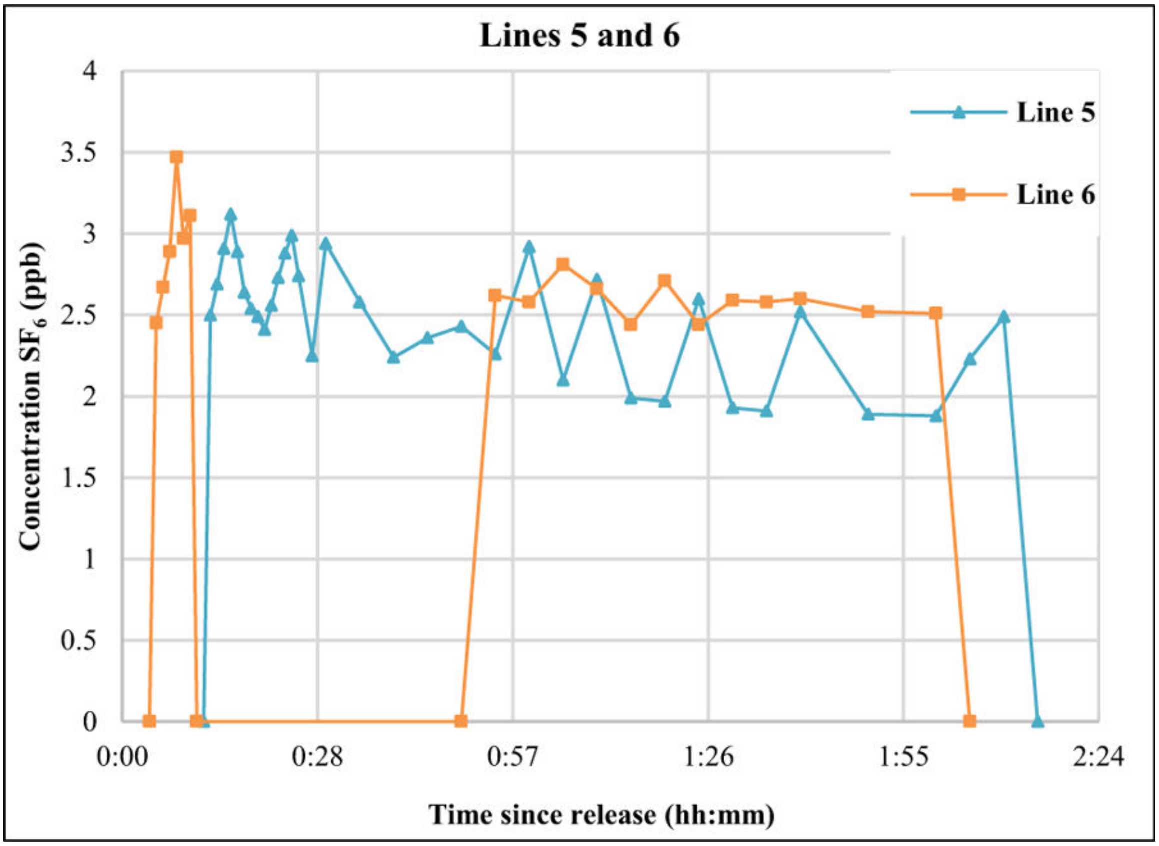

Fig. 5.
Tracer gas concentrations determined for sampling during face test over test duration, sample lines 5 and 6. The arrival and peak occurred on line 6 located inby the face in the former, first tailgate gateroad, prior to the arrival and peak on sample line 5 at shield 177

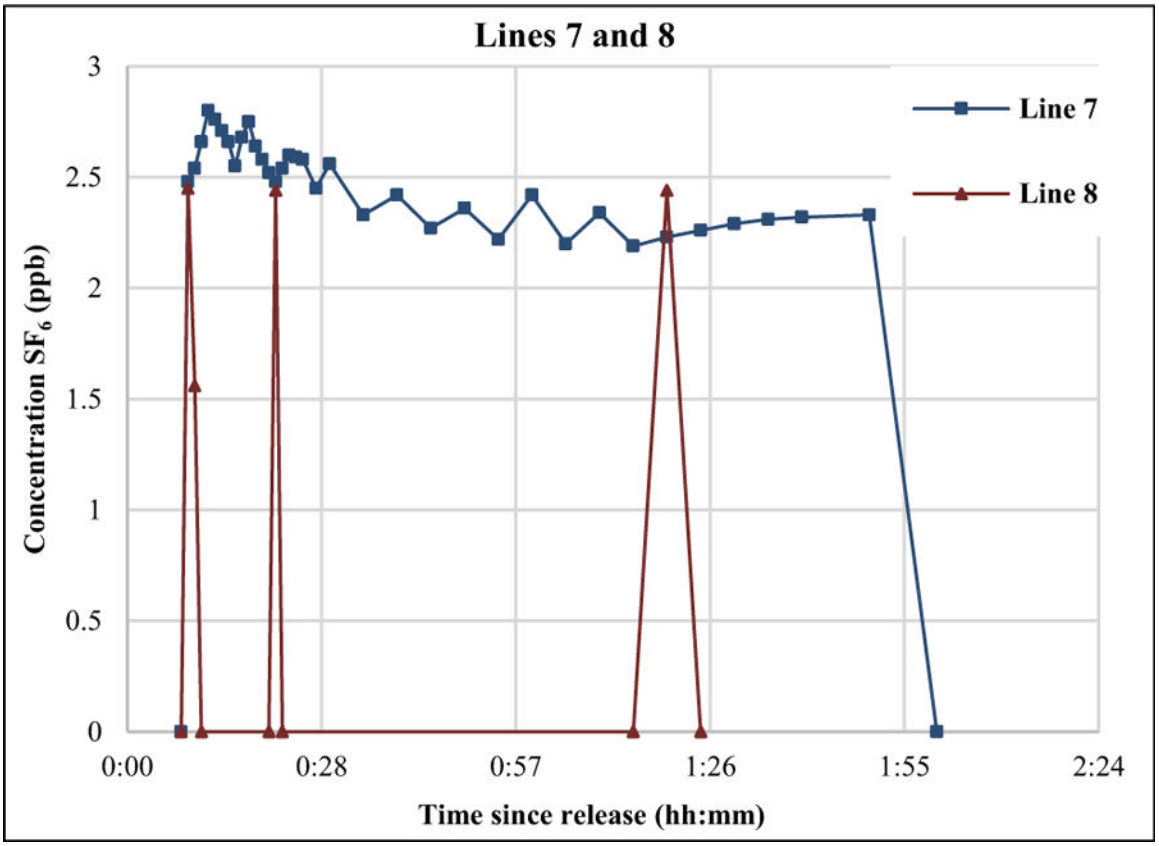

Fig. 6.

Tracer gas concentrations determined for sampling during face test over test duration, sample lines 7 and 8. The analysis from sample line 8 samples show limited data above the detection limit. More continuous measurements were made on sample line 7, the outby location of tailgate gateroad 1

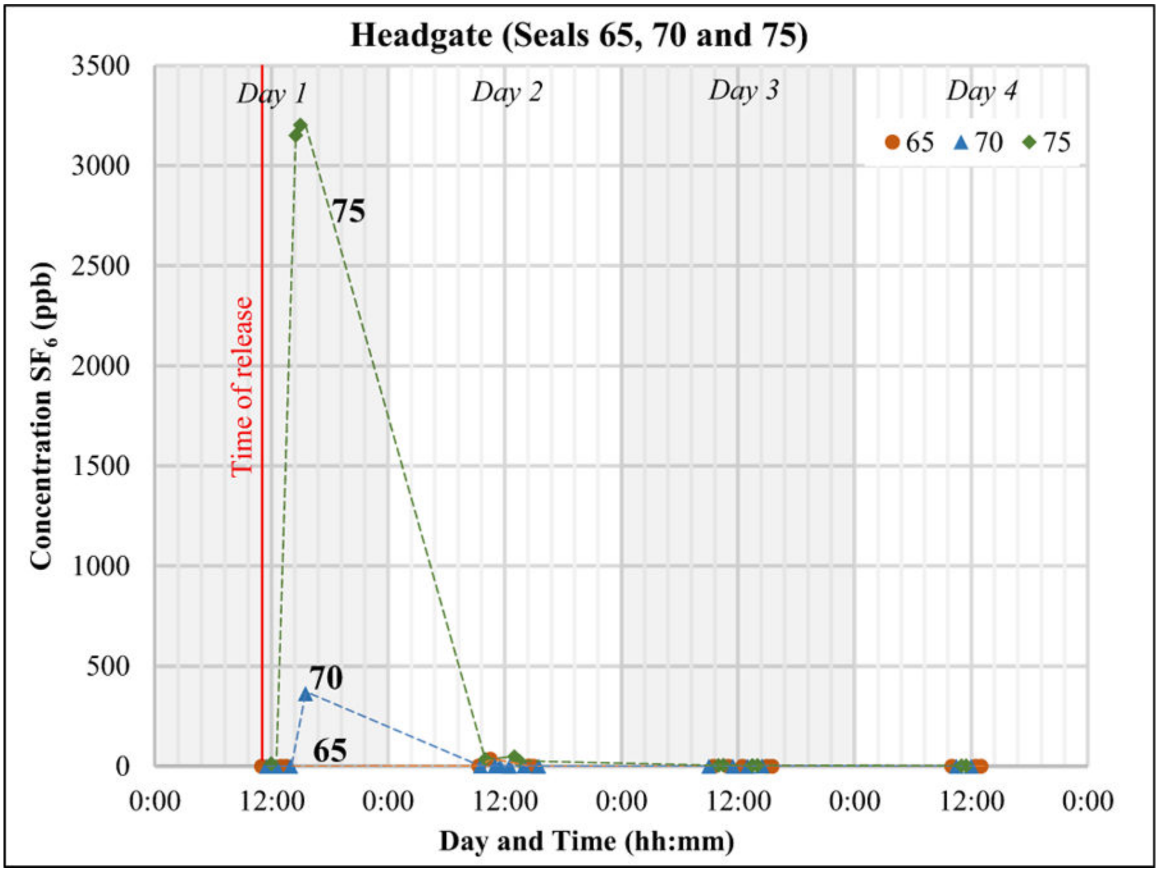

Fig. 7.

Tracer gas concentrations determined for sampling during gob test from headgate locations nearest to the face

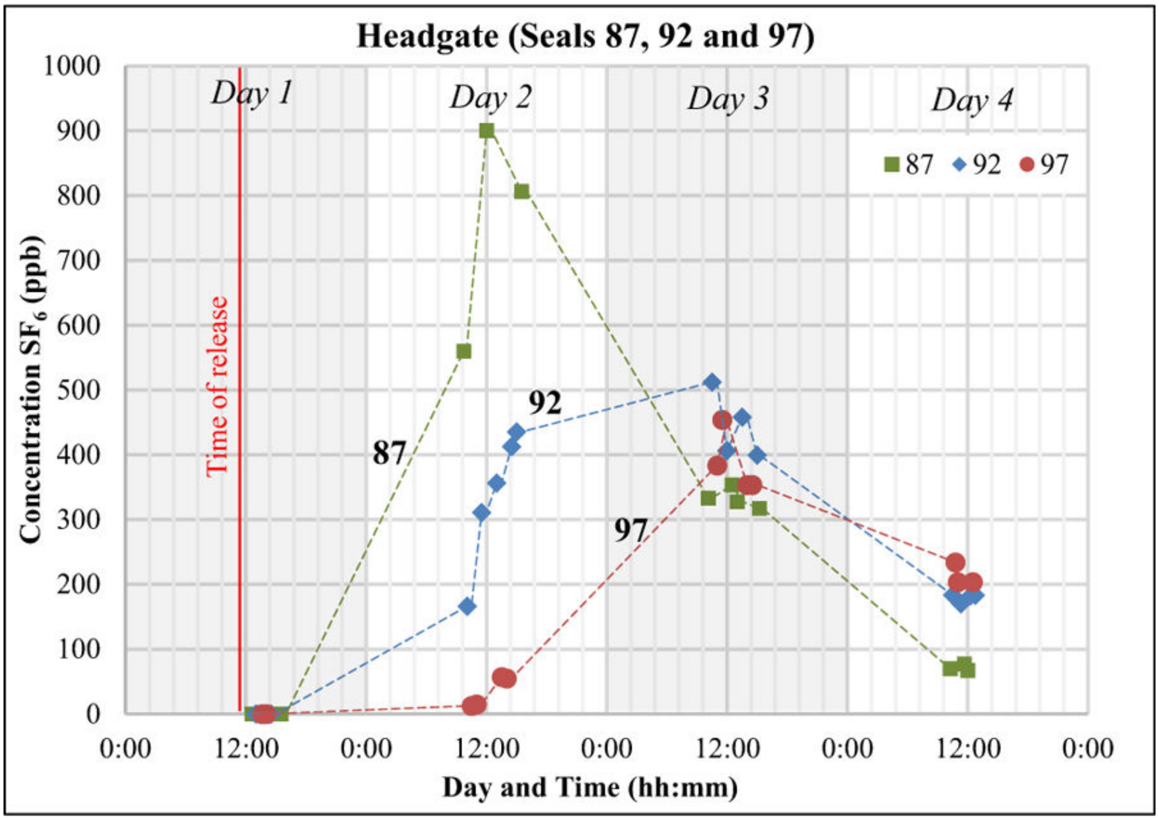

Fig. 8.

Tracer gas concentrations determined for sampling during gob test from headgate locations at the inby set of monitoring locations, seals 87, 92, and 97

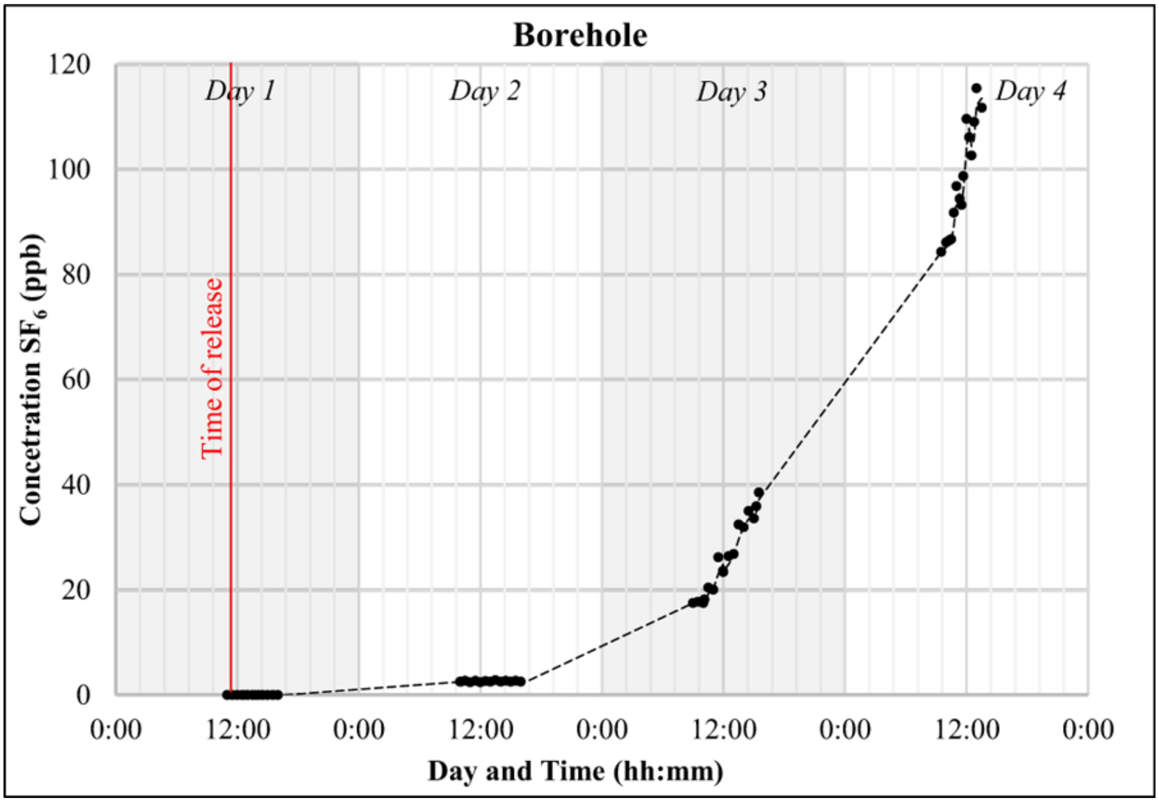

Fig. 9.

Increasing concentrations of SF_6 measured at the surface borehole site during the gob test

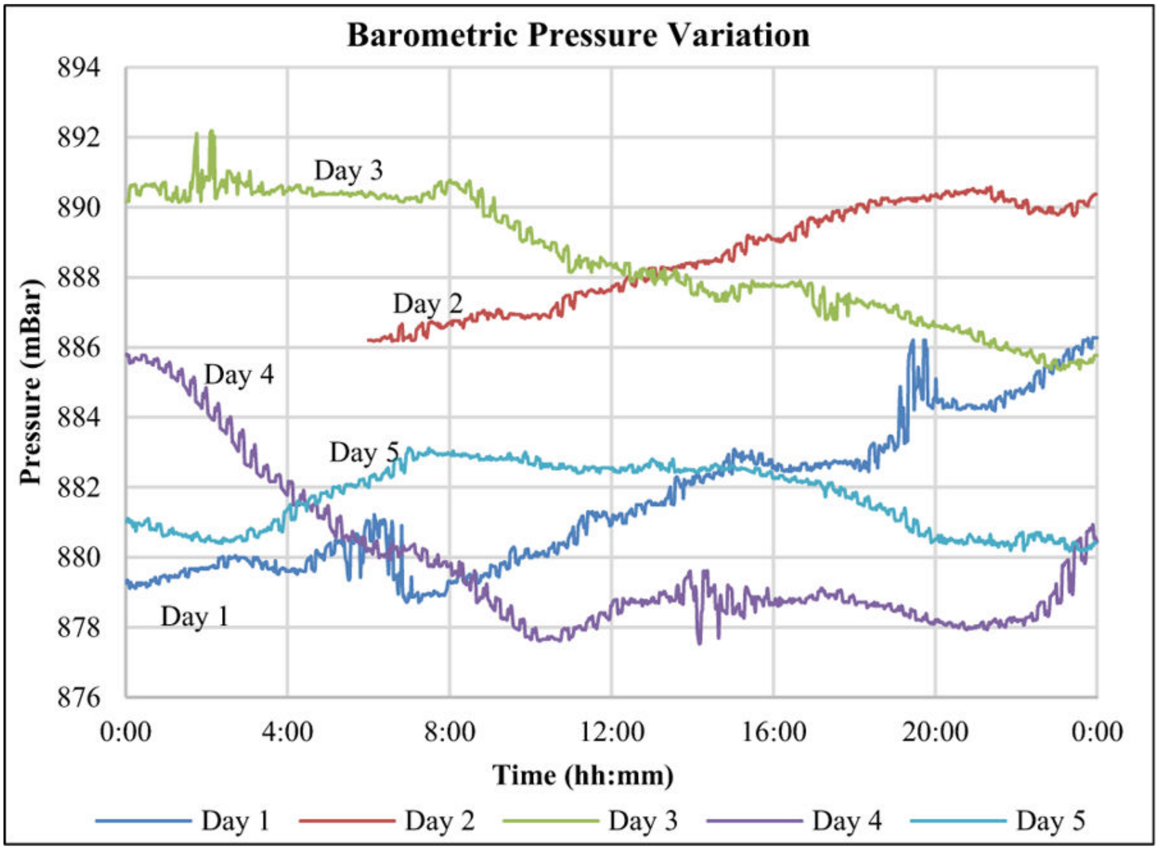

Fig. 10.

Barometric pressure data measured at the surface from study site during tracer gas testing of the gob

Table 1

Average nitrogen production and flow to the 340-kPa (50-psi) seals on the study panel headgate during tracer gas testing and monitoring intervals Units and values are displayed correctly below.

Day	N_2 purity (%)	m^3/s	SCFM
1	95.95	0.224	475
2	95.94	0.219	465
3	96.06	0.217	460
4	96.06	0.207	438
5	96.17	0.218	462

Table 2

Face area and airflows for the study site

Location	**Velocity (m/s)**	**Area (m^2)**	**Flowrate (m^3/s)**	**Flowrate (kcfm)**
Line 1, shield 9	2.59	18.8	48.6	103.1
Line 2, shield 47	3.46	13.8	47.8	101.3
Line 3, shield 93	3.06	15.8	48.3	102.3
Line 4, shield 139	2.83	17.3	49.0	103.8
Line 5, shield 177	2.97	18.8	55.7	118.1
Line 6, inby	Inaccessible		12.5	26.4
Line 7, outby	1.17	21.1	24.6	52.1
Line 8, inby	Inaccessible		18.7	39.6

Table 3

Tubing lengths and transport rates for sampling gases near the study panel face

Location	Length (m)	Pump rate (L/min)	Volume (L)	Transit time (min)
Line 1, shield 9	152	5.00	13	3
Line 2, shield 47	152	5.00	13	3
Line 3, shield 93	305	4.76	26	5
Line 4, shield 139	457	4.30	39	9
Line 5, shield 177	457	4.70	39	8
Line 6, inby	152	5.00	13	3
Line 7, outby	152	5.00	13	3
Line 8, inby	152	5.00	13	3