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Tube bundle system studies at Signal Peak Energy Bull Mountains #1 Mine

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Abstract

A tube bundle system (TBS) is a mechanical system for continuously drawing gas samples through tubes from multiple monitoring points located in an underground coal mine for analysis and display on the surface. The U.S. National Institute for Occupational Safety and Health (NIOSH), in collaboration with Signal Peak Energy (SPE), LLC, Bull Mountains No. 1 Mine, operated a TBS during mining of two bleederless, longwall panels. This paper describes the gas analysis data and its interpretation. As verified by the TBS, coal at the SPE mine tends to oxidize slowly. It was known that a reservoir of low-oxygen concentration atmosphere developed about 610 m (2,000 ft) behind the longwall face. A bleederless ventilation system facilitates formation of an inert atmosphere in this longwall gob and decreases the likelihood of spontaneous combustion. Connections of the mine atmosphere to the surface through subsidence cracks could allow airflow into the longwall gob, revive coal oxidation and increase spontaneous combustion risk. The atmospheric composition of the sealed areas was homogeneous, except in the immediate vicinity of suspected ingassing points. The TBS verified that gases within the partially sealed, bleederless longwall gob expanded into the longwall tailgate area when barometric pressure decreased. The concentration of carbon dioxide in the back return airflow at the longwall tailgate was observed to increase by a factor of three and possibly up to 10 times the typical background concentration of 0.5 to 1.0%, depending on the size of the longwall gob and the magnitude of barometric pressure decrease. TBS have the inherent disadvantage of slow response time due to travel time of the gas

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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.

samples and sequential gas analyses. A TBS or similar continuous monitoring system could be beneficial in detecting and providing warning of potentially hazardous gas concentrations, if the slow response time of the system is always understood.

Keywords

Coal mining; Health and safety; Tube bundle system; TBS; Ventilation

Introduction

A tube bundle system (TBS) is a mechanical system for drawing gas samples from multiple locations in an underground coal mine to the surface and directing samples sequentially to a gas analyzer. The TBS for continuous monitoring of mine atmospheric conditions is a well-developed technology (Litton, 1983) and is deployed at most longwall coal mines in Australia (Brady et al., 2009), but at only one U.S. mine (Bessinger et al., 2005). As part of its research program aimed at introducing potentially beneficial safety technology into U.S. coal mines, the U.S. National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) acquired a TBS from the Safety in Mines Testing and Research Station (SIMTARS) in Brisbane, Queensland, Australia. This Australian TBS was installed at the Signal Peak Energy, LLC, Bull Mountains No. 1 Mine, (SPE), which is located about 64 km (40 miles) north of Billings, MT. The TBS has been operating there continuously since April 2010.

A complete description of this TBS, including the history of TBS, and the hardware, software, operation and maintenance, and cost and manpower for a TBS, is found in a related paper (Zipf et al., 2013). The current paper describes the deployment of the TBS at SPE and discusses the data collected during the mining of two bleederless longwall panels.

Signal Peak Energy Mine

Figure 1 shows the layout of the SPE mine. Mining prior to 2008 developed the east-trending mains, which range from five to seven entries wide, and the 1 South room-and-pillar panel, which is seven entries wide. SPE began longwall mine development in 2008 by extending the existing mains to the east, extending the 1 South entries as a tailgate, and mining the 1 Right entries as a headgate. The 1 Right longwall panel is 381 m (1,250 ft) wide and 4,878 m (16,000 ft) long. The 2 Right longwall panel is also 381 m (1,250 ft) wide but 6,707 m (22,000 ft) long. Future mining will extend the mains further to the east. About 30 more longwall panels are planned along the right (south) and left (north) side of the mains. Mining of the 1 Right longwall panel began in December 2009 and finished in April 2011. Mining the 2 Right panel began in May 2011 and was completed in July 2012. While mining these first two longwall panels, SPE used an exhausting ventilation system.

Initially, the 1 Right longwall panel had a wraparound bleeder system around the longwall gob; however, in August 2010, mining operations switched to a bleederless system due to the risk of spontaneous combustion in the longwall gob. In a bleederless system, the longwall gob is isolated from the ventilating air by seals and stoppings constructed around the perimeter of the longwall panel as it is mined. The atmosphere within a bleederless longwall gob will tend to become oxygen deficient and not supportive of spontaneous combustion. The changeover to a bleederless system occurred when the panel had been mined about 1,220 m (4,000 ft). The face was located near sample point 4 in Fig. 1. Gob isolation seals were built along the 1 Right headgate from the startup room down to the longwall face, and a set of seals was built across the 1 South tailgate near sample point 4. As the bleederless 1 Right longwall panel retreated, additional gob isolation seals were constructed along the headgate, and gob isolation stoppings were constructed across the tailgate entries between each set of crosscuts, as shown in Fig. 2 (right side). The 2 Right longwall panel was always bleederless. Gob isolation seals were built along the 2 Right headgate entries, and gob isolation stoppings were constructed across the tailgate entry in 1 Right as the panel retreated as shown in Fig. 2 (left side).

In April 2010, SPE installed the first eight gas sampling points, as shown in Fig. 1 in the 1 South entries—i.e., the tailgate of the 1 Right longwall panel. Table 1 summarizes the location of each sample point. Sample points 1, 2 and 3 monitored the mine atmosphere near the 1 Right panel tailgate and moved with the longwall face. Monitoring points 4 through 7 were stationary and remained deep within the sealed 1 Right longwall gob as the panel retreated. Sample point 8 was also stationary and monitored the atmosphere in the mines main returns. In April 2011, SPE installed eight more gas sampling points in the 1 Right entries—i.e., the tailgate of the 2 Right longwall panel. Sample points 9 and 10 monitored the mine atmosphere near the 2 Right panel tailgate and moved with the longwall face. Monitoring points 11 to 14 and 16 were stationary and monitored the atmosphere in the 1 Right panel at first and, then, the 2 Right panel after that face passed. Sample point 15 monitored the atmosphere leaving the tailgate of the 2 Right panel.

Figure 2 shows detail of the 1 Right and 2 Right tailgate areas and the location of the sampling points behind the gob isolation stopping (GIS) and the mix point regulator. The GIS sample point is within the sealed area, and the mix point is in the back return airflow, which is not considered to be a travelable, work area. The 1 Right longwall panel had an additional sampling point in the longwall return airflow. As the longwall panel was retreat mined, a new gob isolation stopping and new mix point regulator were constructed after passing each crosscut, and these sample points were also advanced by cutting the sample lines.

At these monitoring points, the TBS provided continuous gas analysis data for oxygen, carbon monoxide, carbon dioxide and methane. At the SPE mine, the methane concentration is below the detection limits of the TBS analyzer, which is 0.1%. Methane concentrations above this limit have not been detected so far. Analysis of gas samples from within sealed areas with a gas chromatograph has detected up to 20 ppm methane and no ethane. Again, this methane concentration is far less than the 1,000 ppm detection limit of the TBS analyzer.

Behavior of oxygen and carbon monoxide in bleederless longwall gob at SPE

Figure 3 shows oxygen and carbon monoxide concentration at the mix point of the 1 Right longwall panel from April 2010 until its completion in April 2011. A bleederless ventilation system was implemented in August 2010, after the panel had been mined about 1,220 m (4,000 ft). For the next three months, carbon monoxide concentration increased and would occasionally climb into the 40 to 50 ppm range for periods of a few days or less. Other gas analysis data not presented here showed that the atmosphere behind gob isolation stopping around the perimeter of the partially sealed bleederless panel converged on a composition of less than about 10% oxygen and more than about 10% carbon dioxide after three months. Until this reservoir of lower oxygen atmosphere developed in the 1 Right gob, carbon monoxide concentration at the mix point could be high; however, after the atmosphere in the panel converged to a lower oxygen composition, the carbon monoxide concentration decreased to 20 ppm or less and, with few exceptions, has remained at that level or less ever since.

Figure 4 shows oxygen and carbon monoxide concentrations at the mix point for the 2 Right longwall panel from the start of longwall mining in late May 2011 through August 2011. During the first month of mining, carbon monoxide concentration peaked at about 140 ppm for one day; however, subsequent peaks steadily decreased. After one-and-one-half months of mining, carbon monoxide concentration was less than 50 ppm. As with the 1 Right panel, about two months were required for a lower oxygen atmosphere to develop within the partially sealed longwall gob. Once a sufficiently large reservoir of lower oxygen atmosphere formed, carbon monoxide concentration deep within the longwall gob decreased to 5 ppm or less with few exceptions. At the gob isolation stopping of 2 Right panel (data not shown), a maximum carbon monoxide concentration of 150 ppm was observed early in the panel life; however, this maximum concentration also decreased to less than 50 ppm as the longwall gob lengthened.

The coal at SPE mine appears to oxidize slowly to form carbon monoxide and carbon dioxide. The oxidation rate decreases as the carbon dioxide concentration increases and the oxygen concentration decreases. The carbon monoxide does not persist in the longwall gob atmosphere. After a few months, carbon monoxide apparently oxidizes further to carbon dioxide, and the oxidation rate of coal in the longwall gob slows further. It appears that a few months after the beginning of retreat longwall mining, a reservoir of low-oxygen atmosphere develops in this bleederless longwall gob that only permits coal oxidation at a slow rate. Development of an uncontrolled fire or spontaneous combustion event becomes less likely with this bleederless system, which facilitates development of this low-oxygen atmosphere in the longwall gob.

Expansion of gob gases into the longwall tailgate

The longwall panels are bleederless; however, some airflow through the gob still occurs. Most of the airflow on the longwall face flows down the least-resistance path in front of the shields, but some air moves through cavities above and around the caved material behind the shields. Some air can migrate up the caved #3 entry on the headgate side of the longwall panel to the startup room, and then down the caved #1 entry on the tailgate side of the panel. By multiple paths, there is a net migration of gas from the longwall gob toward the tailgate and the gob isolation stopping.

The mix point for the bleederless longwall panels at SPE is located in the back return airflow in the tailgate at the first crosscut behind the longwall face as shown in Fig. 2. The gas analyses at the mix point are cyclic with a period of a few days, which is the time it takes for the longwall face to advance one crosscut. Initially, when the longwall face is right at a crosscut, the mix point is in air with an average carbon dioxide concentration of about 0.04% and an oxygen concentration of about 21%. As the longwall face retreats, airflow from the back return and more gas from the partially sealed longwall gob pass the mix point, as seen in Fig. 2. The oxygen concentration decreases and the carbon dioxide concentration increases until the longwall face reaches the next crosscut. At that time, the mix point is moved forward one crosscut and the cycle repeats. However, two additional factors affect the gas composition at the mix point – namely, the size of the partially sealed longwall gob and changes in the barometric pressure.

As the barometric pressure decreases, gas within the gob expands toward the tailgate, and that gas passes the mix point. As the size of the partially sealed longwall gob increases, more gas in the gob is available to expand, and smaller decreases in the barometric pressure will lead to an equivalent gob gas expansion toward the mix point.

Figure 5 shows the carbon dioxide concentration at the mix point for the 1 and 2 Right longwall panels. This concentration data has two components – a background level between 0 and 1%, and brief spikes of 2% or higher. As the longwall gob in these partially sealed panels grows in size due to mining, the background carbon dioxide concentration increases steadily. In the 1 Right panel, it increased to about 1% when the panel was completed with a length of about 4,878 m (16,000 ft). In 2 Right, it increased to 1% by January 2012, when the longwall gob was about 3,049 m long (10,000 ft). Spikes in carbon dioxide concentration (Fig. 5) appeared about four months after longwall mining of the panels began. It also appeared that the magnitude of these spikes may have increased as the size of the longwall gob increased.

Many of these spikes in carbon dioxide concentration at the mix point appear to correlate with barometric pressure changes associated with passing weather systems. There may also be some correlation with diurnal changes in barometric pressure. Figure 6 shows the carbon dioxide concentration and the barometric pressure in the 2 Right panel from September through November 2011. The red arrows point to times when the barometric pressure decreased by about 1 kPa (4 in. H_2O) and a sudden spike in carbon dioxide concentration occurred. These carbon dioxide increases at the mix point also correlated with lesser carbon dioxide increases in the return airflow from 2 Right panel measured at 1 Right at crosscut 10 with sample line 15.

Changes in barometric pressure appear to explain the majority of the spikes in carbon dioxide concentration. The other contributing factor is the position of the longwall face relative to the mix point. However, because the spikes only develop several months after longwall mining begins, when the longwall gob has a large volume, the likely explanation for these spikes is changes in barometric pressure.

The magnitude of the observed spikes in carbon dioxide concentration ranges from 3 to 10 times the typical background level of 0.5 to 1.0%. The duration of these periods of elevated gas concentration defines the monitoring frequency required to detect them. Most of the spikes appear to last several hours. With 16 operational sample lines, the cycle time for the TBS is about 30 min; i.e., each sample point is analyzed every half hour. This sampling frequency is sufficient to capture and observe these occasional short-duration spikes in gas concentration. Taking one gas reading at the beginning of the working shift is not sufficient to observe these spikes. As shown in Fig. 5, most of the spikes in carbon dioxide concentration range from 2 to 5%, and some range from 5 to 10%. This mix point is in the back return airflow and is not in a travelway or work place.

This gas analysis data of carbon dioxide collected every 30 min by this TBS hints at potential safety problems at underground coal mines in general that can go undetected if the atmospheric monitoring frequency is insufficient. Monitoring more frequently than a preshift examination is more likely to detect these short duration spikes in gas concentration that may or may not present a hazard. The only way to detect the presence of these potentially hazardous conditions is with more frequent monitoring using either a TBS or an electronic gas sampling and analysis system.

Connection of bleederless longwall gob to surface

The exhausting ventilation system at SPE induces air movement from the headgate side to the tailgate side of the longwall. Differential pressure measurements have shown that the longwall tailgate and the partially sealed longwall gob in the active panel are under negative pressure of about -0.5 to -0.6 kPa (-2.0 to -2.5 in. H_2O) with respect to atmosphere. Because of the exhausting ventilation system, subsidence cracks from the longwall gob to the surface could allow airflow into the gob. The data in Fig. 7 shows that this pathway for outside air into the partially sealed longwall gob must exist.

Figure 7 shows gas analysis data from a sample point in the 2 Right longwall panel near the startup room in the tailgate. Longwall mining in this panel started in late May 2011, and this sample line functioned well for several months afterward. As expected, oxygen concentration decreased while carbon monoxide and carbon dioxide concentrations increased in the sealed panel during the first month and a half of longwall mining. In late July 2011, after the panel had retreated about 610 m (2,000 ft), something happened that caused the partially sealed longwall gob atmosphere to return to a composition closer to normal air. Also at this time, the concentrations of oxygen, carbon monoxide and carbon dioxide began to oscillate daily. It appears that a connection to the surface developed and that the rhythmic behavior of the gas composition was due to diurnal changes in barometric pressure, which caused fluctuation of the airflow into the gob through subsidence cracks. In the startup area of this longwall panel, the depth of cover is about 61 m (200 ft), and the mining height is at least 3.7 m (12 ft); therefore, substantial cracks and air pathways to the surface are expected.

These connections to the surface apparently allowed oxygen into the longwall gob, which revived coal oxidation. While the partially sealed bleederless longwall panels tend to develop a low oxygen atmosphere that decreases the risk of a spontaneous combustion event, these connections to the surface atmosphere could reverse this tendency and increase the risk of an event.

Homogeneity of gas composition in sealed longwall panel at SPE

Permanent sealing of the bleederless 1 Right longwall panel occurred in late May 2011, when a set of seals was constructed across the 1 South entries between crosscuts 19 and 20. As shown in Fig. 8, there were five sample lines in the 1 South entries that extended deep within the 1 Right panel on its tailgate side, and four sample lines through gob isolation seals on the headgate side of this panel. Figure 8 shows gas analysis data on Dec. 15, 2011, about seven months after permanent sealing. With the exception of one sample point, the sealed atmosphere reached an oxygen concentration of less than 2%, a carbon dioxide concentration from 19 to 21%, and a carbon monoxide concentration less than 2 ppm. This atmosphere can be described as homogeneous.

Due to the exhausting ventilation system, the permanent seals in 1 South and all the gob isolation seals in 1 Right were outgassing. Depth of cover for the startup room in the 1 Right panel is about 61 m (200 ft). Subsidence cracks on the surface exist, and these cracks appear to be ingassing. Thus, the one sample point near the 1 Right startup room (Line 14 in Fig. 1) has higher oxygen concentration, lower carbon dioxide concentration and higher carbon monoxide concentration than the other sample points.

The existence or not of homogeneity in the atmosphere of a sealed area is not well understood. Differing densities of various gases might lead to layering (vertical inhomogeneity), while ingassing and outgassing of the sealed area might lead to lateral differences in composition (areal inhomogeneity). Diffusion rate, turbulence and flow velocity within the sealed area affect the rate and degree of gaseous mixing in a sealed longwall gob atmosphere. This one dataset at the SPE mine suggests that the atmosphere within a sealed longwall panel tends to become homogeneous in composition within a few months after sealing.

Summary

A TBS was installed at the Signal Peak Energy, LLC, Bull Mountains No. 1 Mine near Billings, MT, which is a new longwall mine. Due to concerns about spontaneous combustion, the mine uses a bleederless ventilation system. Gas analysis data collected at the SPE mine during the mining of two longwall panels and the permanent sealing of one panel provided a detailed glimpse of how the gob atmosphere changes over time and how it interacts with the atmosphere in the active mine. Key observations made for the SPE mine are:

1. Carbon monoxide concentration at the mix point in the tailgate of the bleederless longwall panel is highest when longwall mining begins, and it decreases to about 20 ppm after the panel has retreated about 610 m (2,000 ft) and a large reservoir of lower oxygen concentration atmosphere has formed, as shown in Figs. 3 and 4.

2. Carbon monoxide concentration behind the gob isolation stopping (data not shown) may reach 100 ppm or more when the longwall panel begins, but it decreases to 30 ppm or less as the longwall panel increases in size.

3. Carbon monoxide concentration decreases to 5 ppm or less about 300 m (1,000 ft) behind the gob isolation stopping and deeper into the partially sealed longwall gob. In a sealed gob, the carbon monoxide concentration is less than 5 ppm, as shown in Fig. 8.

4. Coal at the SPE mine tends to oxidize slowly and form a reservoir of low-oxygen concentration atmosphere within a few months after retreat longwall mining begins. The bleederless ventilation system facilitates the development of this low-oxygen atmosphere in the longwall gob, and development of a spontaneous combustion event is less likely.

5. The gas composition of the atmosphere in the sealed area at SPE mine is homogeneous, except near places where atmospheric ingassing occurs through subsidence cracks to the surface, as shown in Fig. 8.

6. Diurnal and weather-system-related barometric pressure variations affect the rate of ingassing into a near surface longwall gob, as shown in Fig. 7. The connections can allow oxygen into the longwall gob atmosphere, which may revive coal oxidation and increase the risk of a spontaneous combustion event.

7. Gases within a partially sealed bleederless longwall panel can expand into the longwall tailgate area when the barometric pressure decreases, as shown in Figs. 5 and 6. The concentration of carbon dioxide at the mix point in the tailgate of the panel can increase by a factor of 3, and possibly up to 10 times the typical background concentration of 0.5 to 1%, depending on the size of the longwall gob and the magnitude of the barometric pressure decrease. These spikes in hazardous gas concentration at key points in the ventilation system are only observable with a continuous gas sampling and analysis system. A TBS or similar continuous monitoring system could detect and provide warning of these potentially hazardous gas concentrations.

TBSs or any other continuous mine atmospheric monitoring systems must answer tough questions to justify their widespread deployment in underground coal mines. Can a system that provides continuous, detailed gas composition information at points throughout the mine atmosphere give advance warning of potentially dangerous conditions in time to take corrective actions? Or, alternatively, will such a system generate false alarms and impinge needlessly on productivity? Considering the rapidity at which a mine atmosphere can change in composition in the area of the longwall tailgate, as shown in Figs. 5 and 6, a continuous atmospheric monitoring system at critical points (for example, in the longwall tailgate area or at bleeder evaluation points) in the mine ventilation system may be essential for coal mine safety. However, it should be noted that because of the sample travel times, a TBS may not provide gas composition data fast enough in some situations. The slow response time of a TBS due to sample travel time and sequential gas analyses must always be understood by safety personnel when using a TBS to detect and warn of a potentially hazardous atmosphere.

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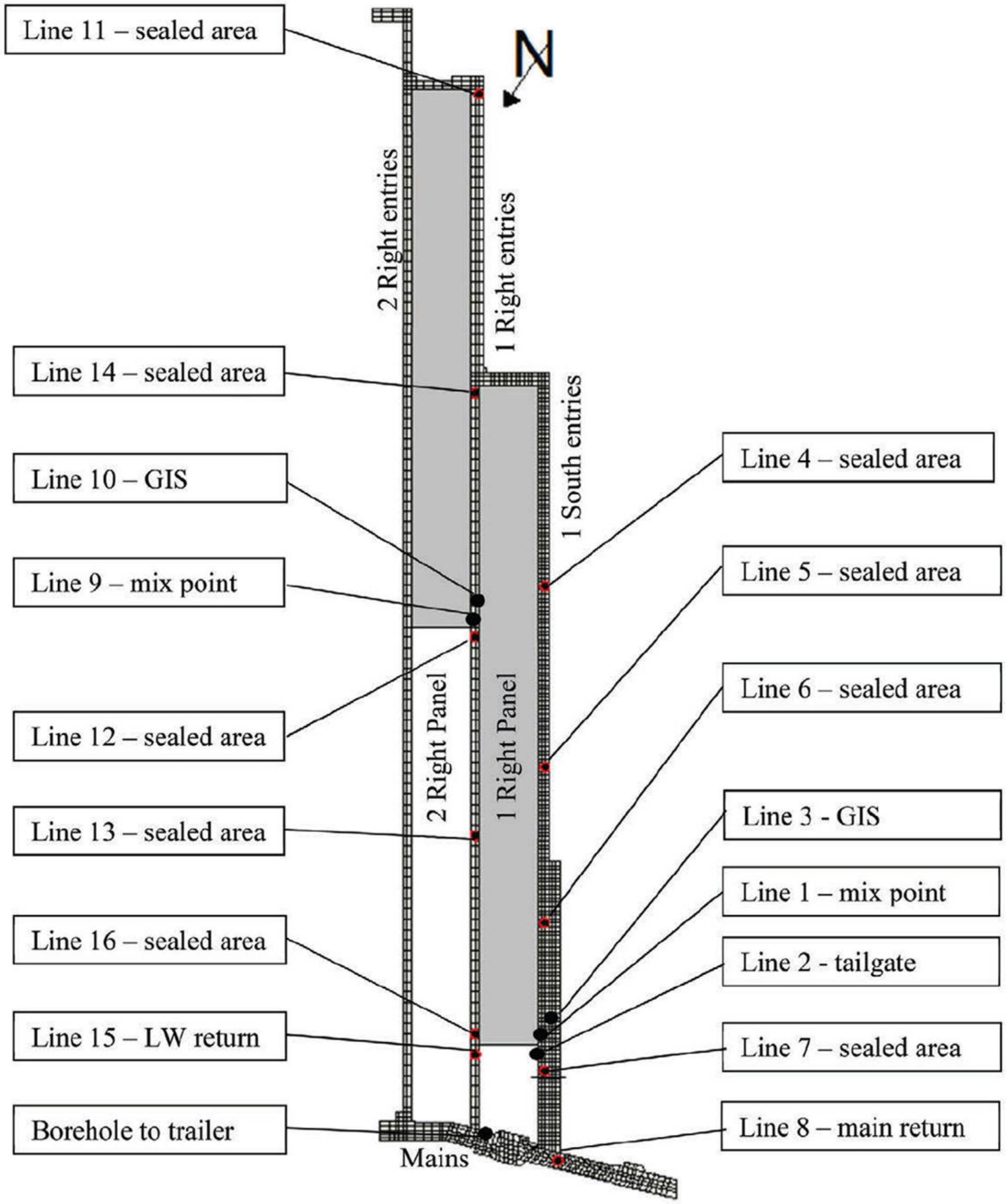


Figure 1.

Mine plan for Signal Peak Energy Bull Mountains #1 Mine showing the mains, the 1 South, 1 Right and 2 Right entries, and the 1 Right and 2 Right longwall panels at about March 2012. Also shown are the sample point locations. Points 1 through 8 were installed in April and May 2010 and operated during the mining of the 1 Right longwall panel, which was completed in April 2011. Points 9 through 16 were installed in April 2011 and operated in the sealed 1 Right longwall panel and while mining the 2 Right longwall panel.

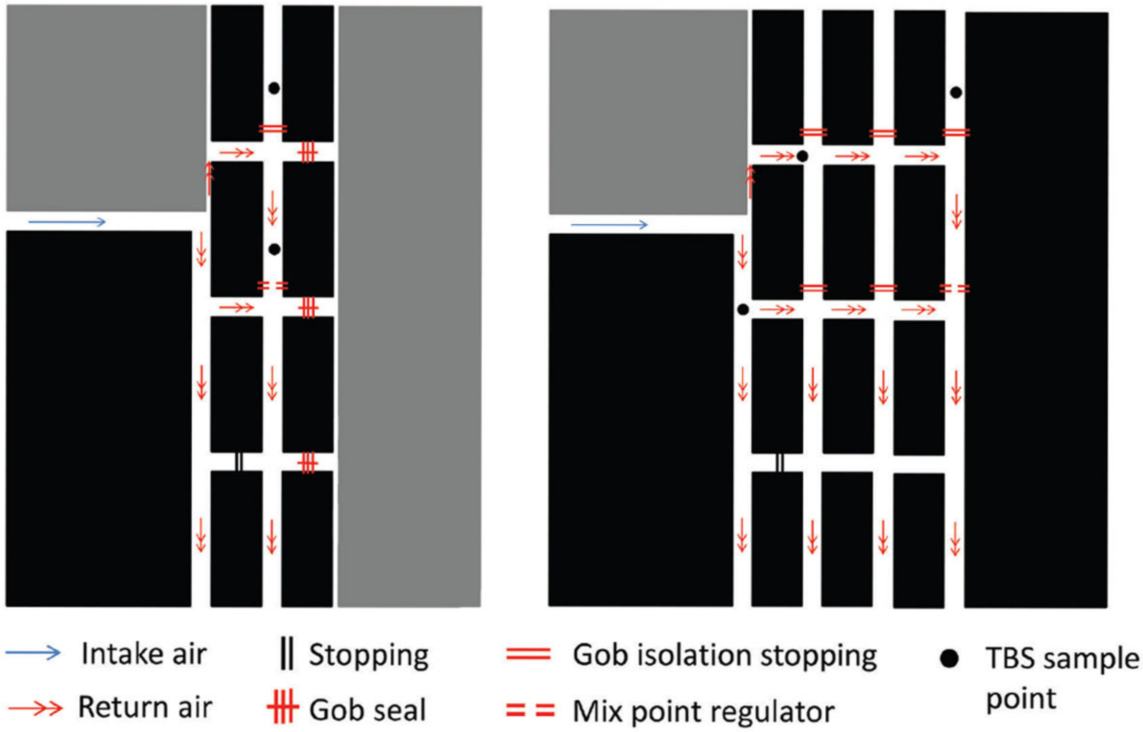


Figure 2.
Schematic of the 2 Right longwall panel tailgate area (left) and the 1 Right longwall panel tailgate area (right) showing gob seals, gob isolation stoppings, mix point regulator, intake and return airflow directions, and the back return airflow at the longwall tailgate. Also shown are the tailgate sample points behind the gob isolation stopping, behind the mix point regulator in the back return airflow, and in the longwall return airflow (1 Right longwall panel only).

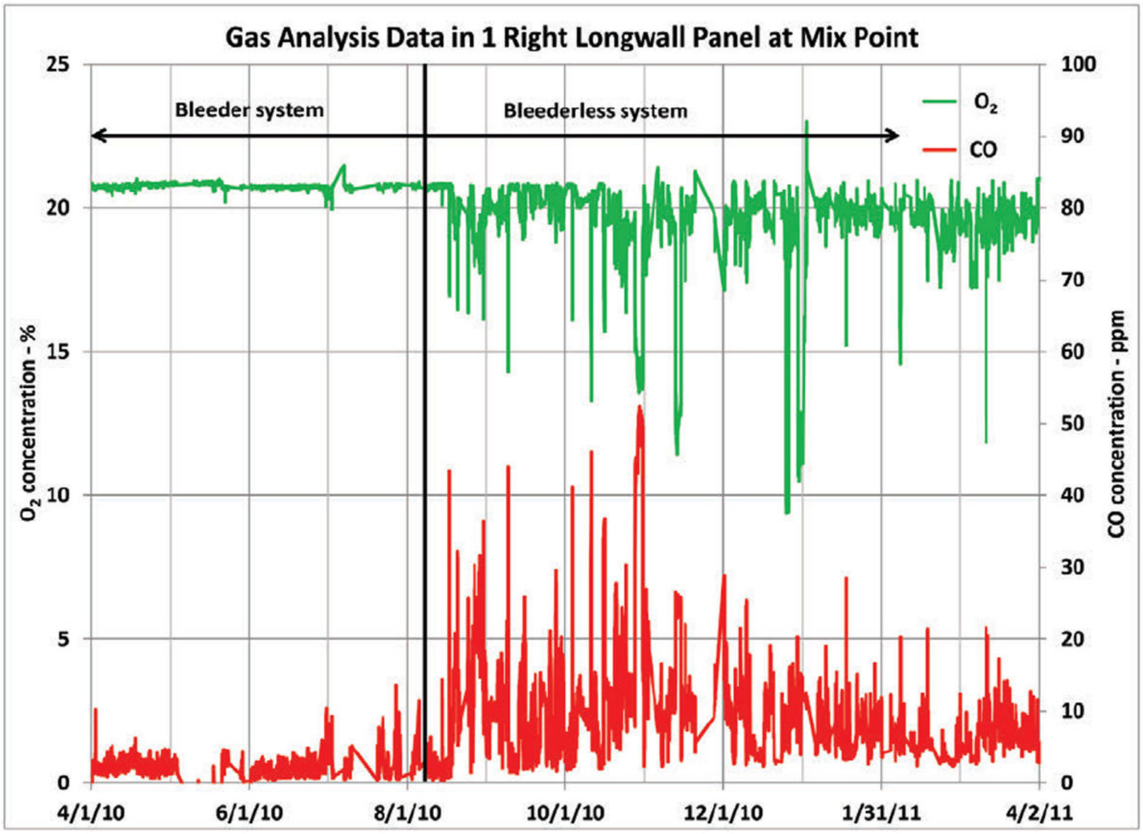
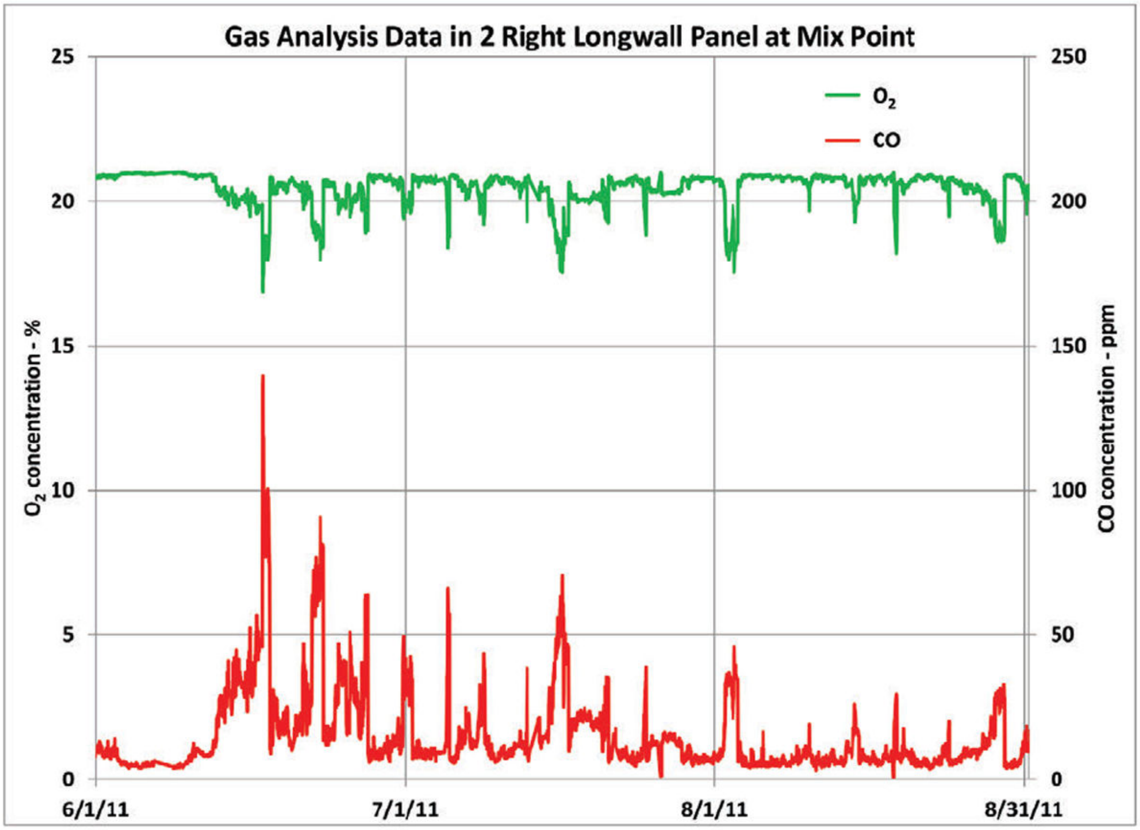


Figure 3.

Carbon monoxide (CO) and oxygen (O_2) concentration data at mix point in 2 Right Panel. Sample point is in the back return airflow in entry 2 in the tailgate behind the longwall face. CO concentrations at this point peaked at 140 ppm and decreased as the mined-out gob became larger.



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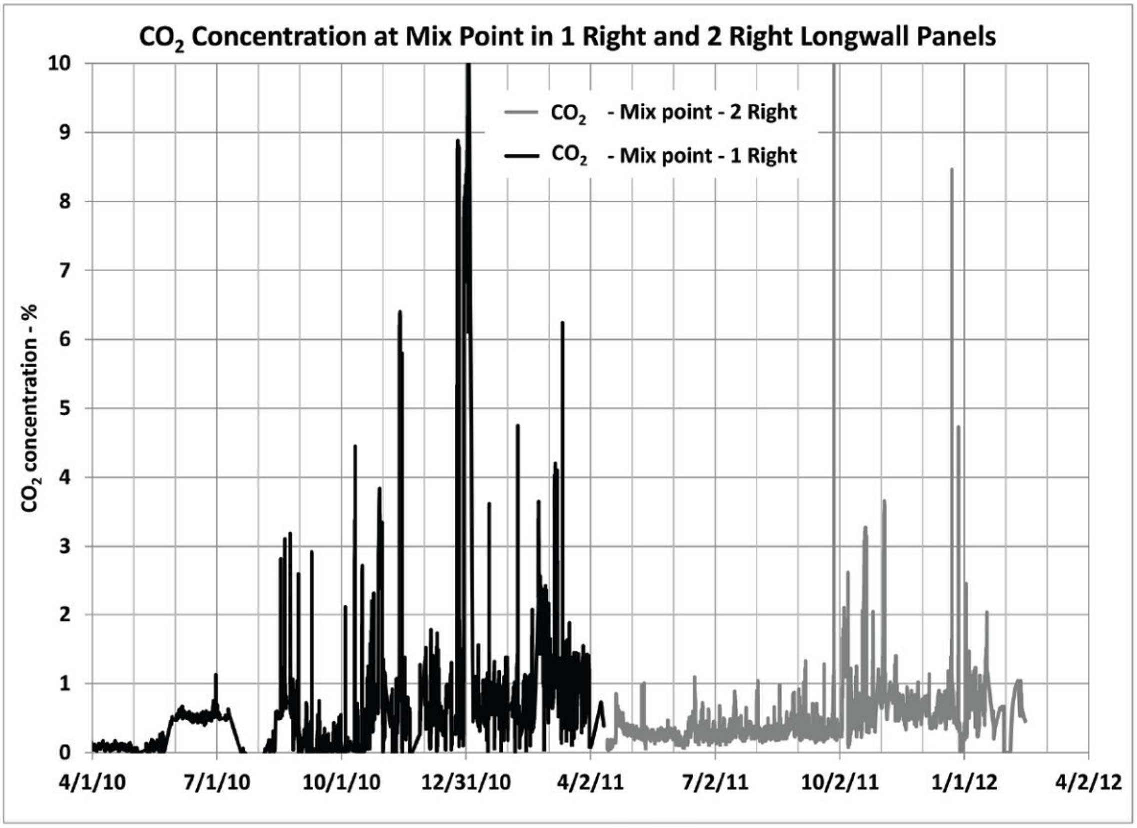

Figure 5.

Carbon dioxide (CO_2) concentration at mix points for 1 Right and 2 Right longwall panels throughout their life.

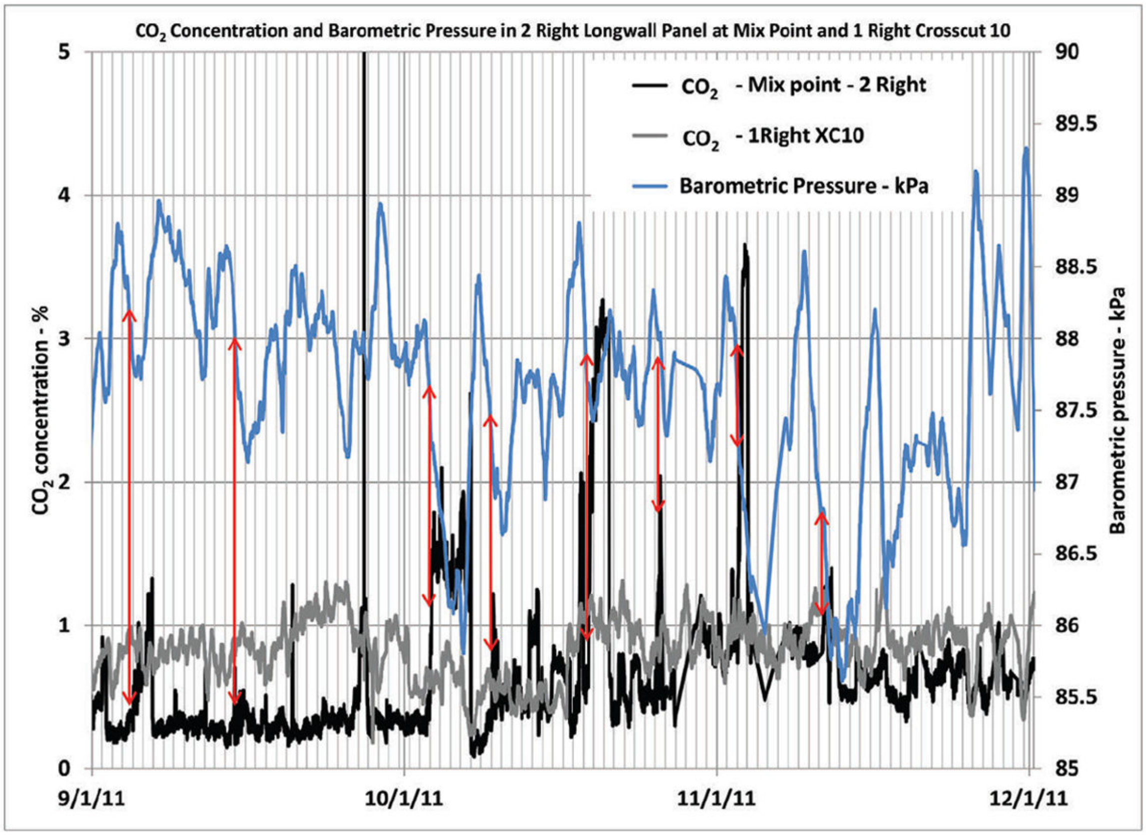

Figure 6.

Carbon dioxide (CO_2) concentration and barometric pressure at mix point in 2 Right panel. Red arrows indicate falls in barometric pressure, followed by an increase in CO_2 concentration at the mix point. These CO_2 increases at the mix point also correlate with CO_2 increases in the return of the 2 Right panel.

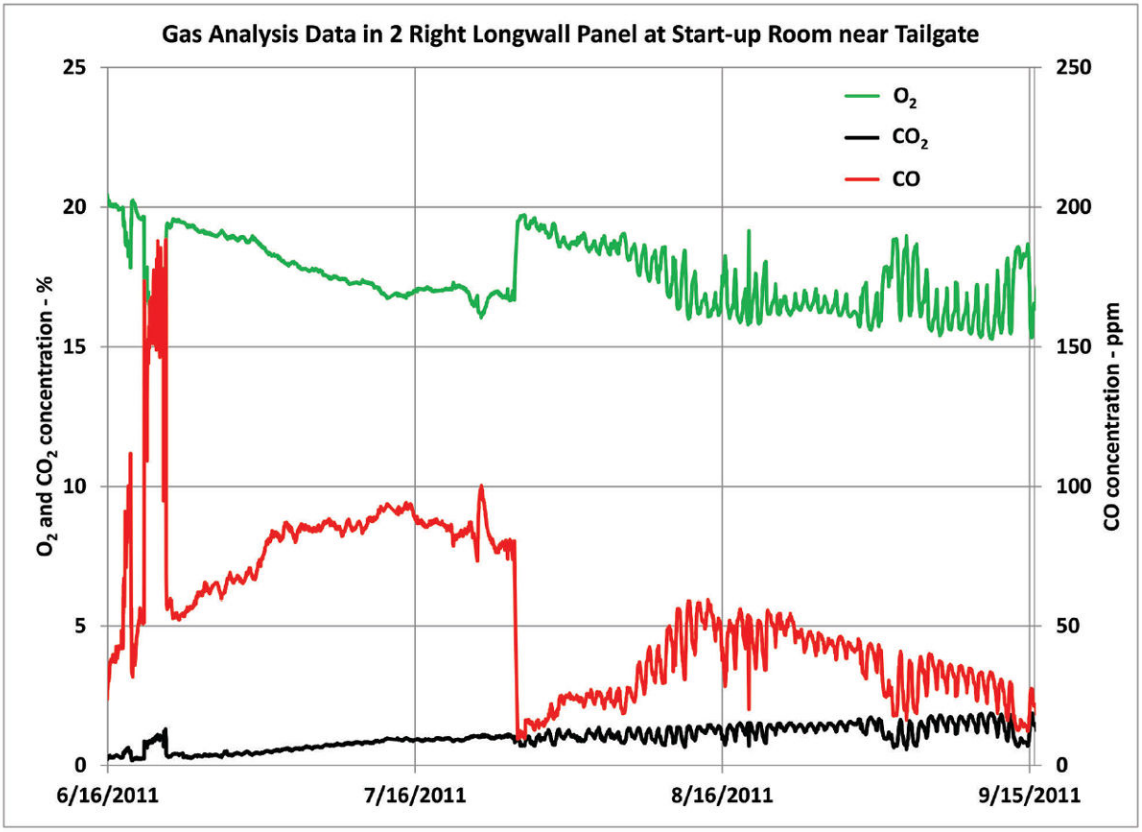

Figure 7.

Oxygen (O_2), carbon dioxide (CO_2) and carbon monoxide (CO) concentration data on the tailgate side of the startup room for the 2 Right longwall panel. In late July 2011, a connection to the atmosphere developed. Note the daily variation in gas composition due to cyclic ingassing.

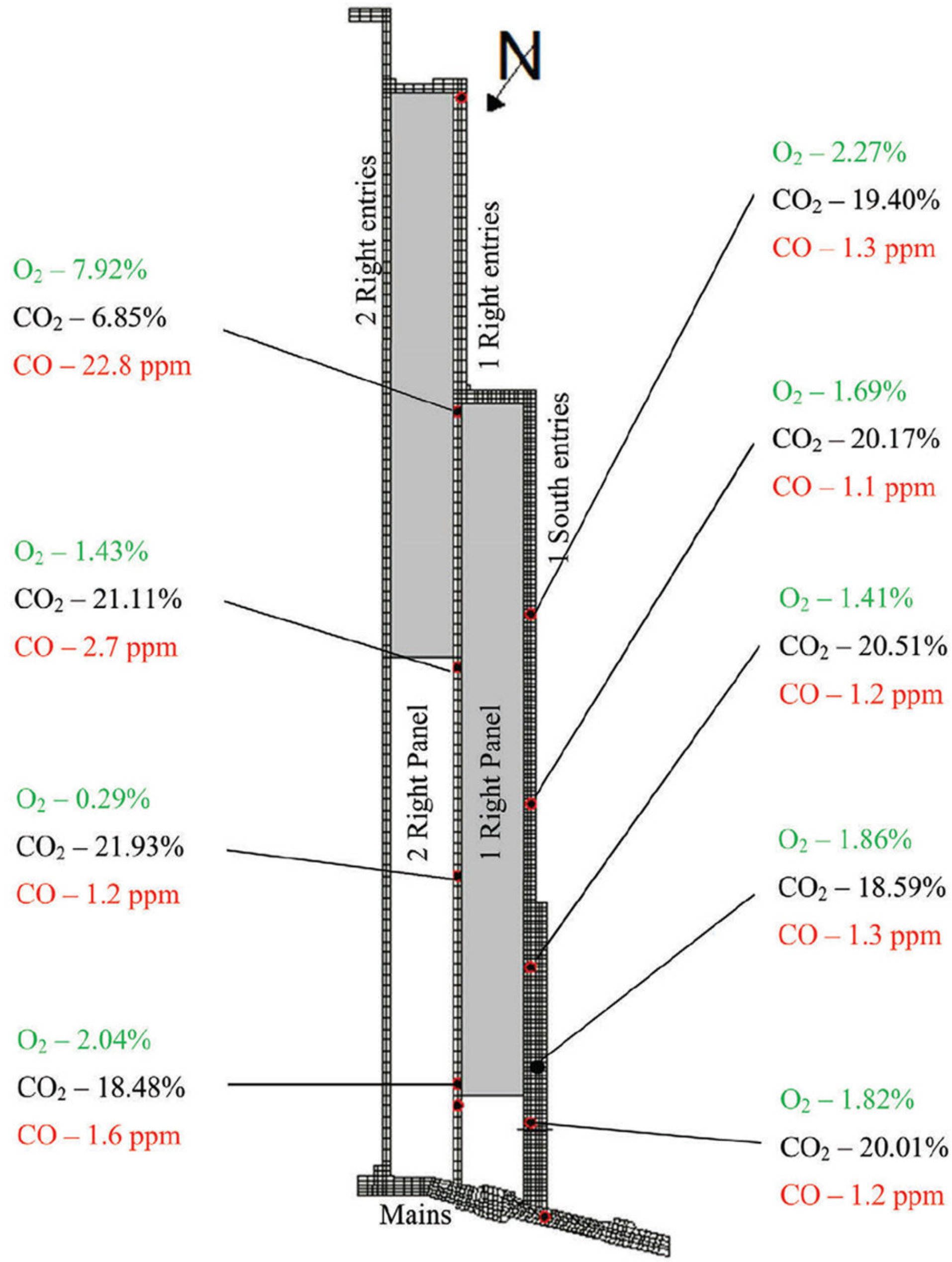

Figure 8.

Mine plan for Signal Peak Energy Bull Mountains #1 Mine at about March 2012. Gas analysis data is on Dec. 15, 2011, about seven months after sealing. The sealed atmosphere is homogeneous with a composition of about 1 to 2% oxygen (O_2), 19 to 20% carbon dioxide (CO_2) and less than 2 ppm carbon monoxide (CO). One data point at the upper left corner of the panel did not follow this overall trend. The atmosphere in this area is communicating with the surface and is ingassing air. At the SPE mine, the methane concentration is zero.

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Table 1

Location of sample points.

Line #	Location
1	Mix point for 1 Right panel in the back return airflow – mobile point (see Fig. 2)
2	Return airflow near 1 Right longwall panel tailgate – mobile point (see Fig. 2)
3	Behind gob isolation stopping (GIS) of 1 Right panel – mobile point (see Fig. 2)
4	1 Right gob – 1 South at crosscut 139 – stationary point
5	1 Right gob – 1 South at crosscut 97 – stationary point
6	1 Right gob – 1 South at crosscut 56 – stationary point
7	1 Right gob – 1 South at crosscut 20 – stationary point
8	Main return of mine – stationary point
9	Mix point for 2 Right panel in the back return airflow – mobile point (see Fig. 2)
10	Behind gob isolation stopping (GIS) of 2 Right panel – mobile point (see Fig. 2)
11	2 Right gob – 1 Right at crosscut 237 – stationary point
12	1 Right gob then 2 Right gob – 1 Right at crosscut 55 – stationary point
13	1 Right gob then 2 Right gob – 1 Right at crosscut 34 – stationary point
14	1 Right gob then 2 Right gob – 1 Right at crosscut 82 – stationary point
15	Return airflow from 2 Right panel – 1 Right at crosscut 10 – stationary point
16	1 Right gob then 2 Right gob – 1 Right at crosscut 12 – stationary point