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Tube bundle system:

for monitoring of coal mine atmosphere

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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. The gas samples are drawn via vacuum pump to the surface and are typically analyzed for oxygen, methane, carbon dioxide and carbon monoxide. Results of the gas analyses are displayed and recorded for further analysis. Trends in the composition of the mine atmosphere, such as increasing methane or carbon monoxide concentration, can be detected early, permitting rapid intervention that prevents problems, such as a potentially explosive atmosphere behind seals, fire or spontaneous combustion. TBS is a well-developed technology and has been used in coal mines around the world for more than 50 years. Most longwall coal mines in Australia deploy a TBS, usually with 30 to 40 monitoring points as part of their atmospheric monitoring. The primary uses of a TBS are detecting spontaneous combustion and maintaining sealed areas inert. The TBS might also provide mine atmosphere gas composition data after a catastrophe occurs in an underground mine, if the sampling tubes are not damaged. TBSs are not an alternative to statutory gas and ventilation airflow monitoring by electronic sensors or people; rather, they are an option to consider in an overall mine atmosphere monitoring strategy. This paper describes the hardware, software and operation of a TBS and presents one example of typical data from a longwall coal mine

Introduction

The tube bundle system (TBS) for monitoring of mine atmospheric conditions has been used in coal mines for more than 50 years and is a well-developed technology. Figure 1 is a simplified schematic of a TBS. Gas samples are collected at various points in an underground mine, drawn to the surface through tubes using vacuum pumps, and then analyzed with a gas analyzer. Chamberlain et al. (1974) described a TBS for monitoring the atmosphere in British coal mines for early detection of spontaneous combustion. Fink and

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Disclosure

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. Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Adler (1975), Hertzberg and Litton (1976, 1978), Litton (1983) and Sengupta (1990) describe the design for a TBS using readily available components. These conceptual designs of the TBS from 30 years ago are identical to that described here; however, the hardware and software have been developed and improved.

Australia has become the leader applying TBS technology in coal mining. After the Moura No. 2 disaster, which killed 11 miners in 1994 (Roxborough, 1997), Australian regulatory authorities and the Australian coal mining industry implemented major safety changes to ensure a nonexplosive atmosphere in coal mines, including the sealed areas. To meet the atmospheric monitoring requirements (Lyne, 1998), most underground coal mines in Australia use a combination of three systems to manage the underground mine atmosphere – real-time, telemetered electronic sensors, a TBS and gas chromatography. The typical TBS at an underground coal mine in Australia will sample from 30 to 40 points in both sealed areas and the active parts of mines (Brady et al., 2009). About half the points sample the atmosphere within sealed areas to make sure they are inert and that spontaneous combustion is not developing. The other sample points are within the general body of the mine ventilation system, and again, they are primarily looking for indicators of spontaneous combustion.

TBS have been used at underground coal mines around the world; however, aside from a few publications in the 1970s and 1980s (see above), there is little published information documenting these applications. China has several TBS installed, and at least two are Australian designs (Brady et al., 2009). A Chinese company supplies TBS to its coal industry (East and West Analytical Instruments, 2013), but the extent of TBS deployment at its underground coal mines is not known. Some European nations, including Germany, Poland and the U.K., also deploy TBS in many of their underground coal mines; however, the number of underground coal mines is small and continues to decline. Underground coal mines in India and South Africa do not deploy TBS routinely. Deployment of TBS in other significant coal mining countries, such as Russia, Kazakhstan and Indonesia, is not known. In the U.S., with about 38 longwall mining operations, TBSs are installed at two – the BHP-Billiton San Juan coal mine near Farmington, NM (Bessinger et al., 2005) and the Signal Peak Energy, LLC, Bull Mountains No. 1 Mine, (SPE), as described in this paper. As mentioned earlier, almost all of the approximately 30 longwall mining operations in Australia deploy a TBS similar to the one described herein.

As part of a research program aimed at investigating potentially beneficial safety technology for U.S. coal mines, the 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. OMSHR installed this TBS at SPE, which is located about 64 km (40 miles) north of Billings, MT, where it has operated continuously since April 2010. SPE used the system to look for indicators of spontaneous combustion in the mined-out areas, and NIOSH researchers studied the behavior of the sealed area atmospheres.

Potential mine safety benefits associated with the use of a TBS for monitoring of coal mine atmospheres include early detection of possible spontaneous combustion products, such as carbon monoxide and carbon dioxide, and maintaining sealed areas inert, with oxygen levels below 10%. In a mine emergency, electronic sensors will eventually fail to provide data once the power is exhausted or turned off, or if the data transmission system is compromised. A TBS might continue to provide mine atmosphere data, if the sampling tubes are not damaged. However, the reliability of that data will be questionable and will require careful evaluation when making mine rescue and recovery decisions.

TBSs are not common in U.S. coal mines. This paper describes how TBSs work, including their hardware, software, operation, maintenance, cost and manpower requirements. One data set obtained with the TBS at SPE is presented to show how a bleederless longwall gob became inert. Finally, the potential safety benefits of a TBS are discussed.

Hardware

Figure 2 (Simtars, 2009) is a schematic of a typical 40-point TBS. Figure 3 is a picture of the inside of the trailer that houses the TBS presently deployed at the SPE mine. The TBS hardware performs as follows:

1. Draws gas samples continuously from all sample lines at all times with purge pumps.
2. Directs gas samples sequentially to an analyzer using a programmable-logic-controller (PLC) and solenoid valves.
3. Analyzes gas samples for carbon monoxide, carbon dioxide, methane and oxygen (typically).

Sample lines (Fig. 4) are deployed throughout the underground coal mine to the sample points. This installation uses 16- mm (5/8-in.) OD by 13-mm (1/2-in.) ID low-density polyethylene (LDPE) tubing. Sample lines up to 7,622 m (25,000 ft) long are practical with this line diameter. Vacuum-type compression fittings are required to splice sample line segments. The sample lines are deployed underground by hanging them singly or as a group from roof bolts or the roof mesh. The sample lines are brought to the surface through a borehole (Fig. 5) and enter the trailer through a panel on the back wall.

Three purge pumps (Fig. 5) draw continuously on all sample lines. By pumping on all sample lines all the time, the latest-possible gas sample is always available at the solenoid valves inside the trailer. Inside the gas analysis trailer, all samples first pass through a particulate filter, a water trap and, finally, a flame arrester, before entering the array of three-way solenoid valves (Figs. 2 and 3). Most of the time, the solenoid valves connect each sample line to the purge pumps, which draw sample gas and then immediately vent it to the atmosphere through an exhaust stack outside the trailer (Fig. 5). When a particular sample line is selected for analysis, the solenoid valve disconnects that sample line from the purge pump and connects it to the sample pump, which delivers sample gas under positive pressure to the gas analyzer.

From the sample distribution panels (Fig. 3), gas samples are routed sequentially to the analysis panel shown in Fig. 6. A PLC controls the operation of the solenoid valves and checks the condition of major system components. From the solenoid valves and sample pump, gas samples first pass through an additional filter, and then enter a sample conditioner located at the bottom of the panel, which removes all moisture from the gas sample. The sample flow leaves the conditioner and enters the gas analyzer located at the top of the panel. For a system with 30 sample points, about 45 minutes are required to cycle through all sample points. The system also records the barometric pressure at the trailer, the sample flow rate through the analyzer, and the vacuum pressure on each sample line. Barometric pressure data may be useful for understanding trends in gas composition at a sample point. The gas analyzer (Sick Maihak Model S715) can measure up to 1,000 ppm carbon monoxide, 30% carbon dioxide, 100% methane and 30% oxygen, all with an accuracy of ± 0.5% of full scale. This analyzer uses an infrared detector for carbon monoxide, carbon dioxide and methane, and a paramagnetic detector for oxygen. It is possible to analyze for other gases, but these gases are widely regarded as the most common earlier indicators for spontaneous combustion or an explosive atmosphere. If desired, it is possible to send sample gas from the TBS to a gas chromatograph for more extensive analysis.

Software

The Safegas software developed by Simtars (2009) performs as follows:

1. Displays analysis data continuously for all monitoring points.
2. Provides notification and gives warnings depending on the current gas analysis data.
3. Archives gas analysis data for subsequent detailed analysis of history and trends.

Safegas is an operating system and it interfaces with the PLC to control the TBS. With it, the operator can select and program the gas sampling and analysis sequence. In most circumstances, the system will simply cycle through all the sample points in sequence; however, any sampling order or frequency is possible. For example, sample points considered more important for safety, such as those in the longwall tailgate area or at a bleeder evaluation point, could be analyzed more frequently. It is also possible to focus on one or a few selected sample points and only conduct gas analyses on these points.

Figure 7 is a screenshot of a portion of the main window for the Safegas operating system. This window is normally on display to the system operator. This display can be distributed via the mine computer network to others interested in the gas analysis data. The window in Fig. 7 shows a schematic of the SPE coal mine layout and the location of each sample measurement point. On the left side of the mine layout are displays of the most recent gas analysis data for each sample point.

The Segas software, also developed by Simtars (2009), is used to plot the gas analysis data. Such plots enable a knowledgeable person to look for trends and discern developing conditions well before a potentially dangerous situation is reached and immediate action is needed.

Operation and maintenance

The trailer containing the analysis system requires less than 10 kW of electric power, mainly to run the purge pumps and for heating and air conditioning. A residential load center (single phase, 120/240 volts, 100 amps, 24 circuits) is adequate.

The sample lines require protection from sunlight, freezing temperatures and mechanical damage from roof falls or moving equipment. For freeze protection underground, locating tubes in a return airway or along the belt lines is better than in the intake airways. The tubing is usually secured on roof bolts or roof mesh along the roof near the center of an entry. Since the sample lines operate under vacuum, compression-type connectors are required for joining sample line segments.

The flow velocity in the sample lines can range from 0.9 to 1.8 m/sec (3 to 6 ft/sec) depending on the length, diameter and condition of the sample tube. The time required for a sample to travel from the sample point in the mine to the gas analysis trailer (called the delay time) can range from 15 min to two hours or more. The “most recent” gas analysis data for a sample point is not the atmospheric composition “now,” but the atmospheric composition from some time ago, when the gas first entered the sample line.

Maintaining a TBS requires some manpower and effort. The gas analyzer, pumps, filters and sample lines require periodic attention. The gas analyzer should be calibrated monthly. The purge pumps and sample pump can last anywhere from nine months to two years under continuous service before needing a rebuild or replacement. Emptying the water traps and changing the filters every few months has been sufficient at the SPE mine.

Frozen sample lines were a problem with this installation at SPE. When a sample line carrying warm, moisture-laden air enters a cold intake entry, condensation occurs inside the sample line, which can freeze and block the sample line temporarily. Blocked sample lines could lead to overheating and failure of the purge pumps. Locating the sample lines in warmer return airways eliminates, for the most part, the problem of sample line freezing.

The LDPE sample lines have survived well in the underground coal mine environment. Small pieces of roof strata falling between roof supports have stretched sample lines by several feet, but they still continued to provide valid samples to the gas analyzer. However, leaks in sample lines do develop. Sudden changes in gas composition might indicate a developing problem in the mine atmosphere or a leaking sample line. The possibility of a leak requires consideration when evaluating the gas analysis data.

Cost and manpower

Capital cost for the TBS shown in Figs. 3, 5 and 6 is about US$350,000 (2009), which includes the gas analyzer, purge pumps, sample pump, solenoid valves, power supplies, PLC, server and client computers, licenses for Safegas and Segas and a 9.8-m-long (32-ft-long) office-storage trailer to house all necessary components. An installation with eight sample lines may require 30,500 m (100,000 ft) of LDPE tube, at a cost of US$10,000, plus another US$5,000 for connector fittings. Total capital cost to deploy this system is about US $400,000.

Manpower requirements are modest. Installing sample lines may take a crew of four persons a few days. However, once the system is operational, manpower requirements are minimal. As mentioned earlier, the system does require some periodic maintenance, such as changing filters, draining water traps and calibrating the gas analyzer. On occasion, sample lines have developed a leak when punctured by equipment impact or small pieces of falling rock. Once the leak is located, splicing the sample line and repairing it with a new coupling is easy. Fortunately, locating leaks has also been easy. Leaks due to equipment impact are most likely at intersections or low points in the roof. Leaks due to a piece of fallen rock are also obvious. All leaks so far have been found and repaired with a few hours of inspection. During the trial period at SPE, this routine maintenance required about two man-days per month.

The most important manpower requirement is for daily examination and interpretation of the gas analysis data to look for trends and identify potential problems with the mine atmosphere early. Examining this data may require about one hour each day by a knowledgeable, technical person.

Example gas analysis data

A TBS provides mine atmosphere monitoring data for each of the mine sample points. As an example of this data, Fig. 8 shows oxygen, carbon dioxide and carbon monoxide concentrations behind the tailgate of a bleederless longwall panel at SPE during the first three months of mining. After about two months, the reactive coal has depleted the oxygen concentration in the partially sealed longwall gob to about 15% or less. During this initial inertization phase, Fig. 8 shows that the carbon monoxide concentration peaked at about 150 ppm; however, it decreased to 75 ppm or less after two months of longwall mining, and remained at that lower level. In this three-month period, the face had advanced about 610 m (2,000 ft) from the start-up room.

Improved atmospheric monitoring strategies for US coal mines

Preventing fires and explosions in U.S. coal mines may require more robust monitoring of the mine atmosphere than is currently practiced. The function of a ventilation system is to provide sufficient air volume to all active workings, intake and return air courses and worked-out areas to dilute, render harmless and remove all contaminants. A monitoring system can verify that the ventilation system performs its functions as designed, and it should include detectors for airflow, ventilation pressure and various gases at multiple points along each branch of the ventilation system. A TBS is one technology option to consider as part of an overall mine atmosphere monitoring strategy.

TBSs have several advantages over electronic sensors. Permissibility is not an issue, since the sample gas is brought to the surface for analysis through the sample lines. The TBS does not have any electronic components underground. If the sample gas composition is outside the range of the gas analyzer, a different analysis method such as a gas chromatograph can be used to determine the gas composition.

TBSs also have disadvantages. A TBS requires installation of sample lines, and these lines may require maintenance. Pumps, filters and other components will also require servicing. When deploying a TBS in cold climates, sample lines should be installed in return airways to minimize problems with frozen sample lines. Gas analysis data from a TBS is not real-time, but contains a delay caused by the gas sample travel time. Therefore, a TBS may not be sufficient to detect rapidly changing conditions in the mine. A TBS cannot be used to monitor airflow, another key parameter in an overall mine atmospheric monitoring strategy.

A potential reason to deploy a TBS is for emergency preparedness. After a mine emergency, such as fire or explosion, all power to the underground mine is usually disconnected and all electronic atmospheric monitors will eventually stop working. If a TBS were in place before a mine emergency, it might continue to provide mine atmosphere composition data, which might enable faster rescue and recovery efforts. However, the reliability of the atmospheric data would be questionable. Sample lines not "hardened" by burying them in the floor or encasing them in concrete may be cut by an explosion and the resulting new sample location will not be precisely known. The TBS would continue to provide near real-time data about the mine atmosphere; however, because of potential sample line breaks, the reliability of the information would be questionable. Therefore, only a knowledgeable person should evaluate and interpret gas analysis data from a TBS post-disaster.

Summary

A TBS is a mechanical system for drawing mine gas samples to the surface through tubes, directing samples to a gas analyzer, and then analyzing the gas for carbon monoxide, carbon dioxide, methane and oxygen. Software for the TBS displays the most recent gas analysis data, notifies the operator and gives warnings of potential problems, and archives the data for subsequent trend analysis. Total capital cost for the TBS as described is about US $400,000.

The TBS is a well-developed technology used in coal mines around the world for more than 50 years. Most long-wall mines in Australia deploy a TBS, usually with 30 to 40 monitoring points. Some of the sample points monitor sealed areas to make sure they are inert. Others monitor the active mine workings to verify real-time gas analysis data from other electronic sensors and to serve as backup in the event of a power outage or disaster. The primary applications of a TBS are detecting spontaneous combustion early in the active coal mine atmosphere and maintaining sealed areas inert.

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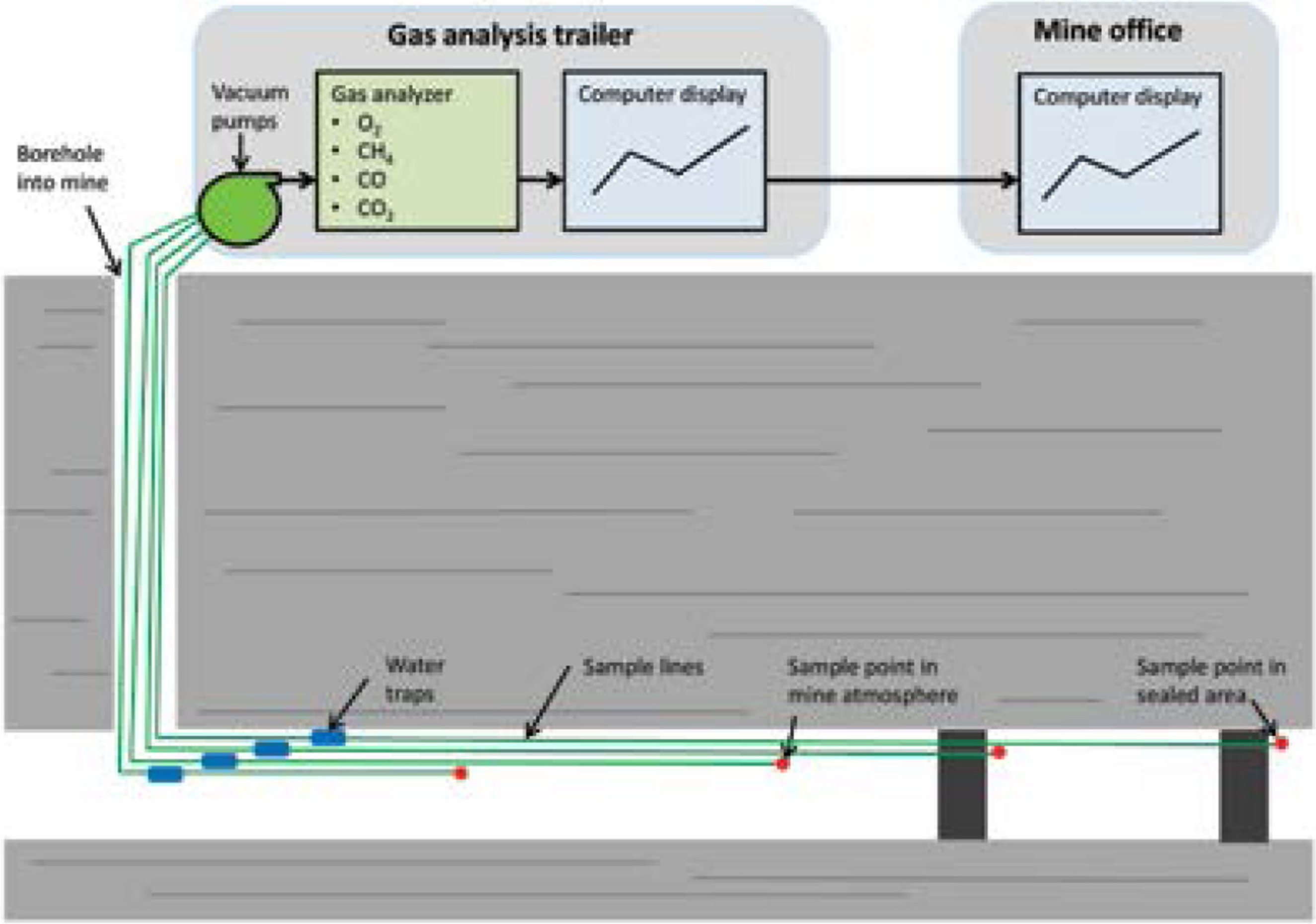

Figure 1.

Simplified schematic of a TBS. Vacuum pumps on the surface draw gas samples from locations in the mine. The gas samples are analyzed and results are displayed in the mine office (Griffin et al., 2011).

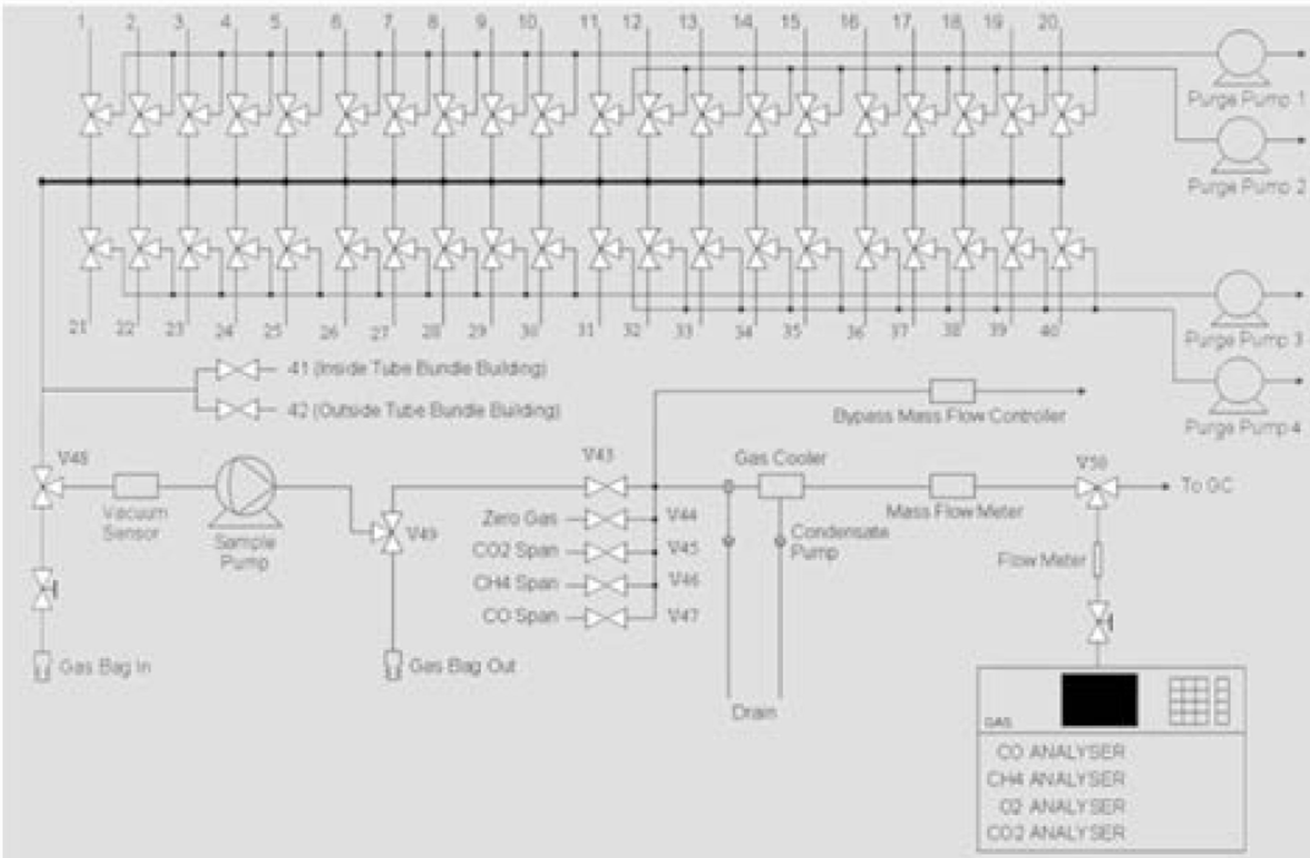

Figure 2.

Engineering schematic for a typical TBS. In this system, up to 40 sample lines can operate. Four purge pumps draw sample gas continuously on 10 lines each. When the solenoid valve is switched to the sample position, the sample pump sends sample gas to the gas analyzer (Simtars, 2009).

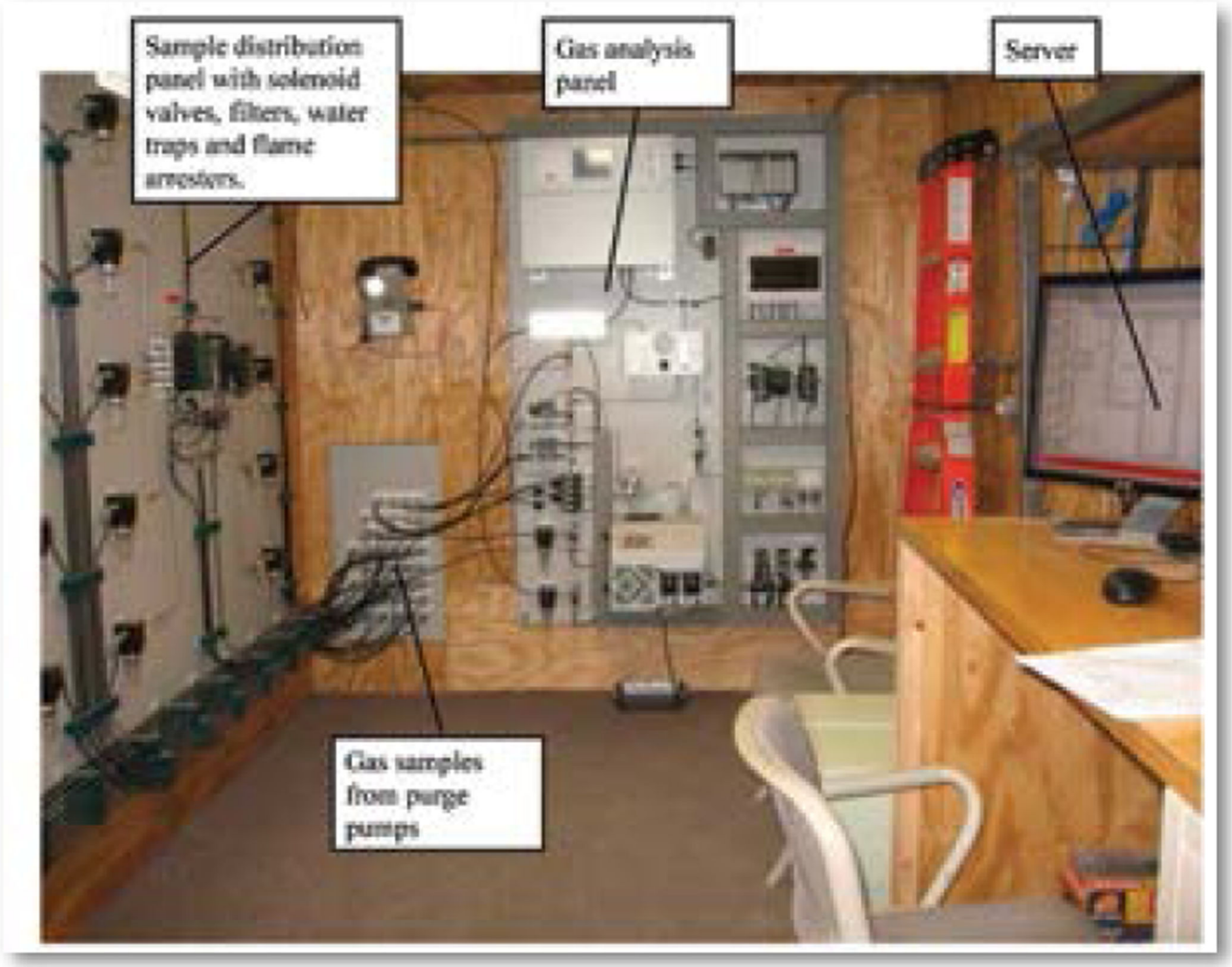

Figure 3.
View inside the NIOSH gas analysis trailer showing the sample distribution panels on the left, the gas analyzer and other components in the center and the server for data analysis on the right.

Figure 4.
Typical sample lines for a TBS in an underground coal mine.

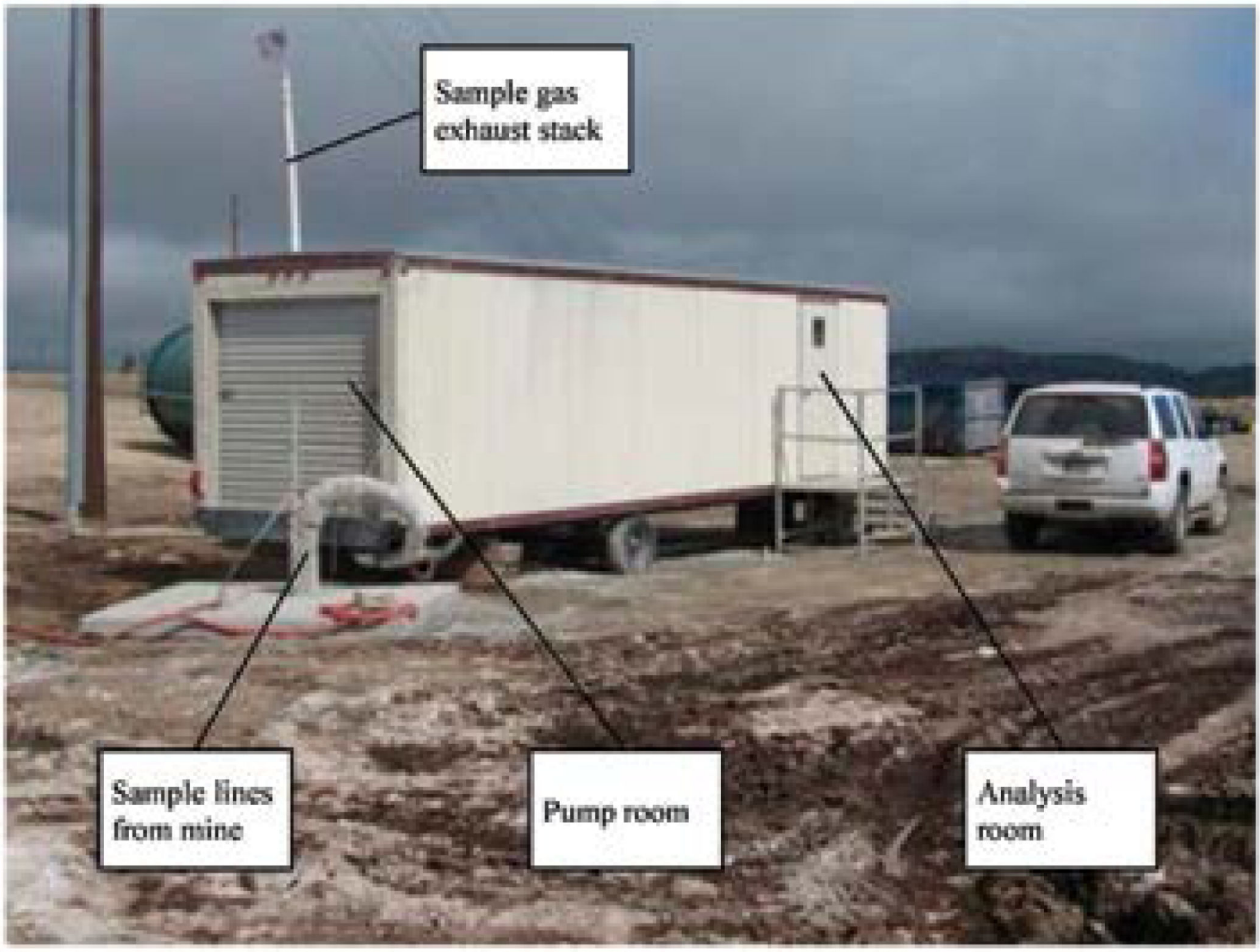

Figure 5.
Outside view of NIOSH gas analysis trailer. Sample lines emerge from a borehole in the concrete pad at left. Purge pumps are at the left in the trailer rear. Sample lines enter the gas analysis room through the panel in the trailer rear. Unused samples are vented into the exhaust stack on the left side of the trailer. The analysis system is housed in the central portion of the trailer.

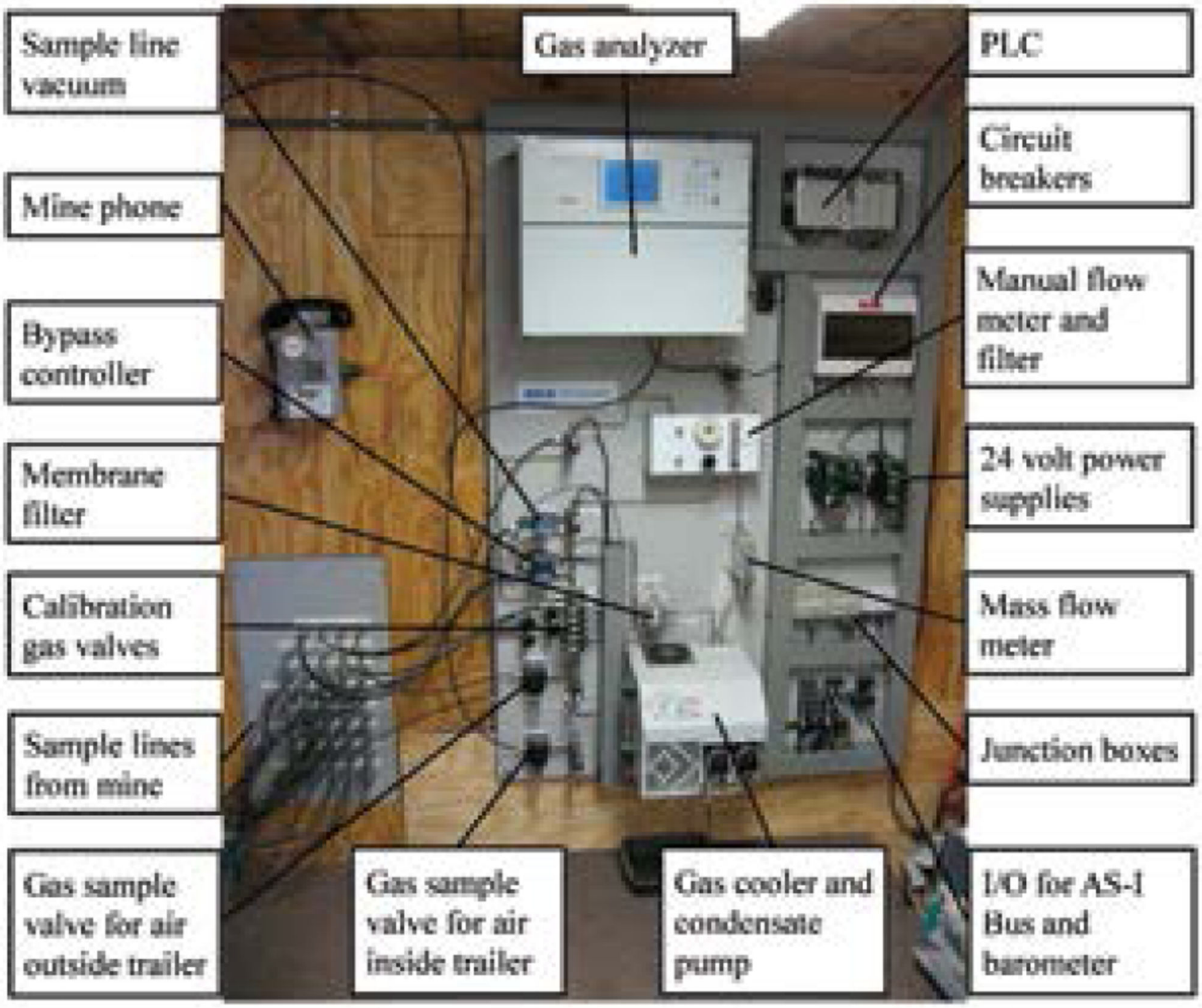

Figure 6.
Closeup of analysis panel in NIOSH gas analysis system and all major components.

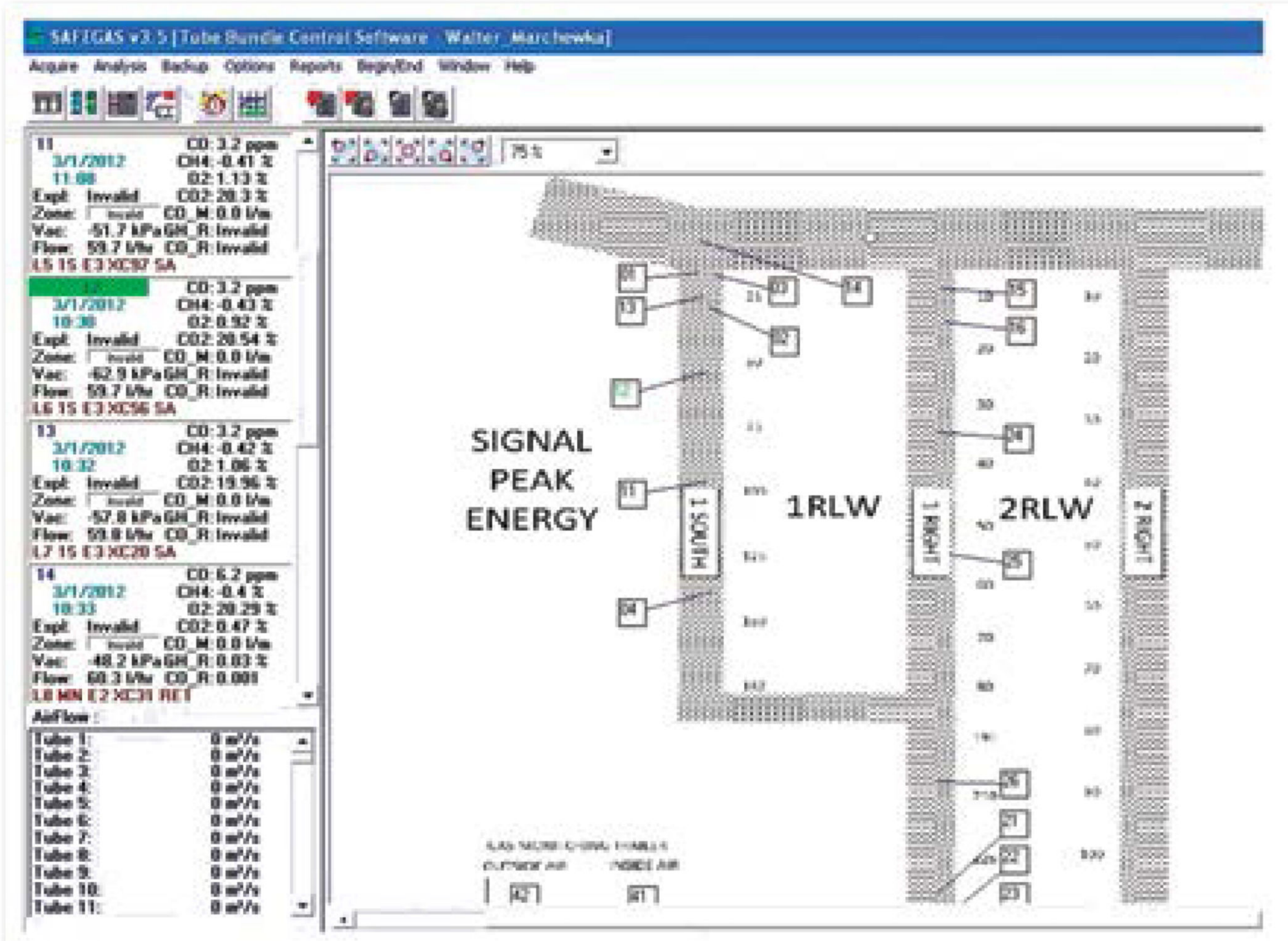

Figure 7.

Partial view of main window for the Safegas operating system showing a schematic of longwall panels at Signal Peak Energy, LLC, Bull Mountains No. 1 Mine and the gas sample point locations. The current data subwindows to the left of the main display show the current gas analysis data for each sample point.

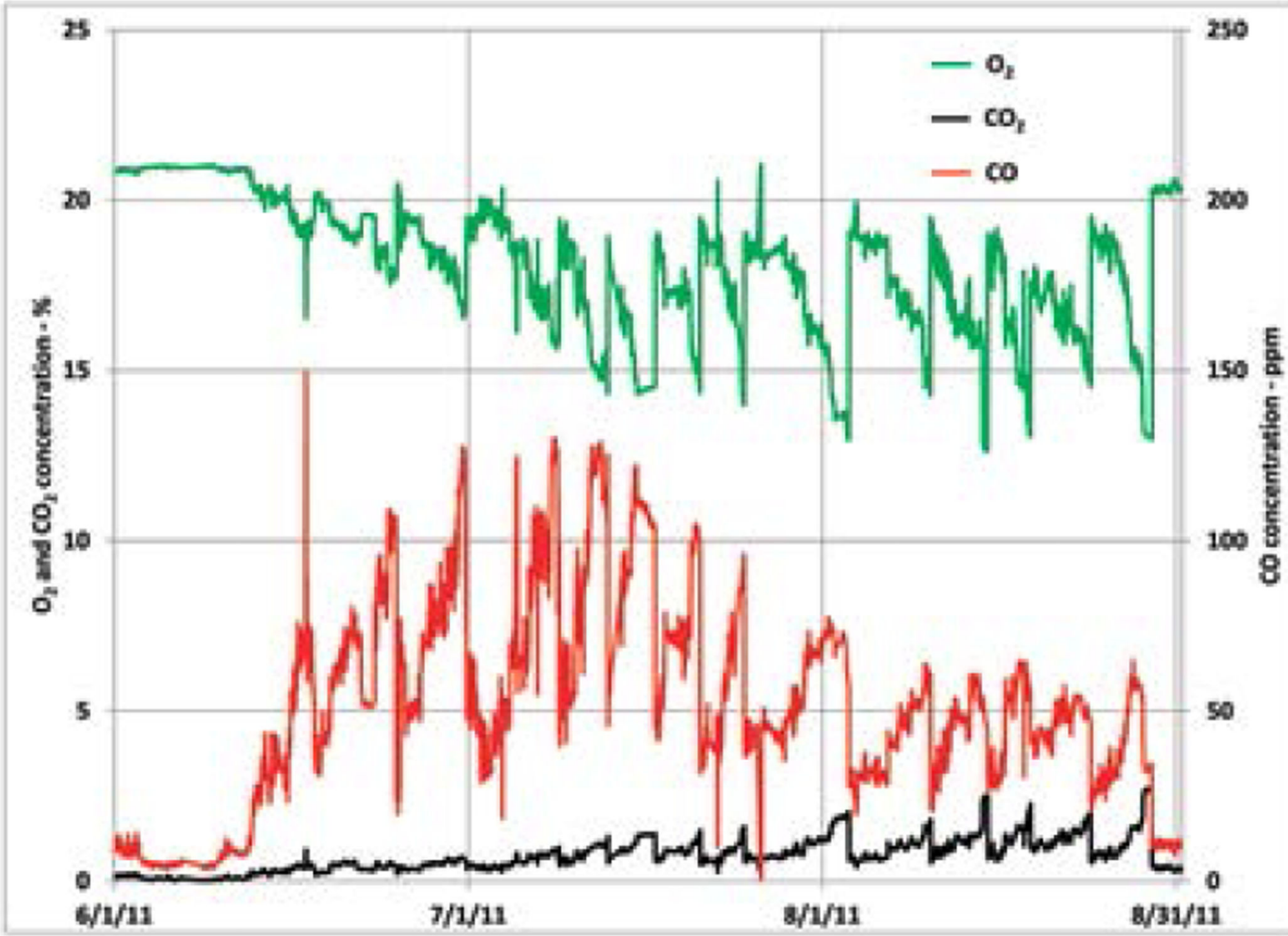

Figure 8.

An example record of mine atmosphere monitoring data from a TBS. Gas analysis data includes oxygen (O_2) concentration (green), carbon dioxide (CO_2) concentration (black) and carbon monoxide (CO) concentration (red). The sample point is located behind the gob isolation stopping in the middle entry of the tailgate one crosscut behind the 2 Right panel longwall face at SPE. CO concentrations at this point peaked at 150 ppm and decreased as the mined-out gob became larger. The gas analysis data is cyclic every 7 to 10 days, as the longwall face is advanced to the next crosscut.