NIOSH Research for Monitoring and Controlling Methane at U.S. Underground Coal Mining Operations

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ABSTRACT: NIOSH research has focused on the monitoring and the control of methane levels in active mine workings. Response times for instrumentation using catalytic heat-of-combustion sensor technology were evaluated. NIOSH research has modelled the flow of methane gas onto longwall faces and gobs, developed engineering controls to limit methane levels during mining, and designed coalbed and gob degasification systems. Available methane control systems have been challenged by recent developments in longwall and room-and-pillar mining systems. This includes increased face advance rates leading to increased productivities, increased longwall panel sizes, and the generally deeper workings of U.S. coal mines. The potentially violent nature of any underground explosion or ignition requires the measurement, control, and reduction of methane emissions into the mine environment for continued worker safety.

1. INTRODUCTION

The liberation of methane into underground workings occurs continuously in all coal mining operations. Early attempts to prevent explosions resulting from the ignition of methane gas resulted in safer explosives, closed lights for illumination, and the development of permissible electrical equipment. Since the middle of the last century, research to prevent explosions and ignitions has focused on controlling the concentrations of methane in active mine workings. Figure 1 shows the injuries and fatalities caused by explosions that have occurred in U.S. coal mines since 1990.

Recent large scale methane explosions in the United States include the July 2000 event at the Willow Creek Mine in Utah (2 fatalities and 8 injuries), the September 2001 event at Jim Walter Resources No. 5 Mine in Alabama (13 fatalities and 3 injuries), and the January 2003 occurrence at the McElroy Mine in West Virginia (3 fatalities and 3 injuries). A frictional ignition in the gob of the Willow Creek Mine in Utah in November, 1998 is considered the most likely source of a widespread mine fire that required the sealing of the mine. Other recent underground explosions have occurred at the Pinnacle Mine in West Virginia in the fall of 2003 and the frictional ignition and subsequent fire at the Buchanan No. 1 Mine in Virginia in February 2005. In January 2006, a methane explosion at the Sago Mine in West Virginia resulted in 12 fatalities and 1 injury. The Darby No. 1 Mine explosion in Kentucky in May 2006 led to 5 miners losing their lives.

Available methane control systems have been challenged by recent developments in longwall and room-and-pillar mining systems. This includes increased face advance rates leading to increased productivities, increased longwall panel dimensions, and the generally deeper workings of U.S. coal mines. The increasing coal productivities from longwall and room-and-pillar operations can lead to greater volumes of coalbed methane gas entering the underground mine environments from exposed coal surfaces and from cut coal on the conveyor belting. Production advances in underground coal mining can sometimes outpace existing systems for methane control. Due to the potentially violent nature of any underground explosion or ignition, control and reduction of methane emissions into the mine environment in necessary for continued worker safety. This paper provides a review of recent NIOSH research for monitoring and controlling face gas levels in longwall and room and pillar extraction systems.

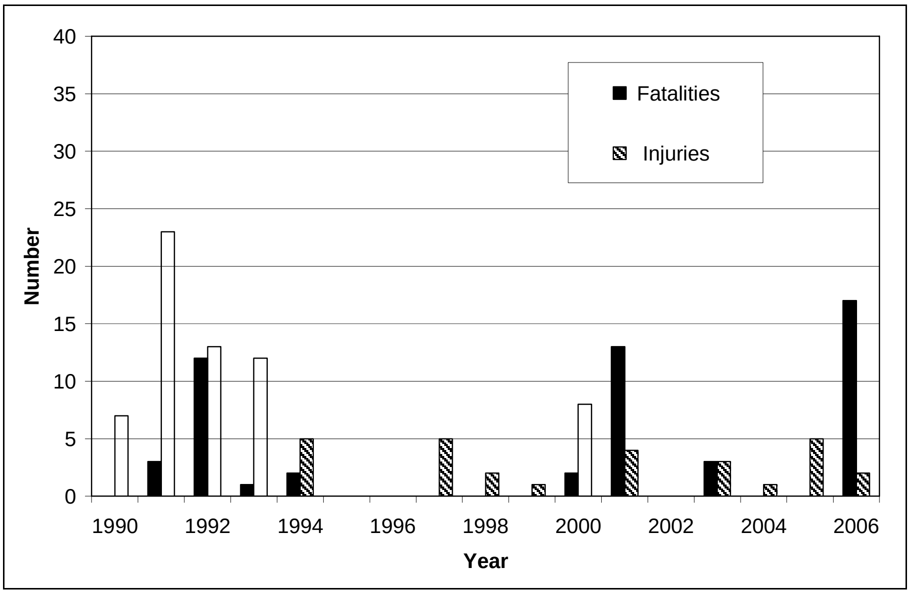

Figure 1. Number of injuries and fatalities caused by explosions in underground coal mines

2. NIOSH RESEARCH IN METHANE MONITORING

To ensure the safety of underground coal mine workers, methanometers are mounted on continuous or longwall mining equipment to monitor methane levels. Machine-mounted methanometers are tested and approved by the Mine Safety and Health Administration (MSHA), the regulatory agency for the US mining industry. These monitors alert face workers when methane levels reach 1 pct and remove power to the mining equipment when levels reach 2 pct.

The ability of a monitor to provide protection depends upon the accuracy of the reading and the response time of the device to changes in methane levels. Calibration procedures are specified by the equipment manufacturers and US mining law requires that mine operators check the calibration at least once every 31 days. Response times determine how quickly methanometer readings change to reflect current concentrations. When a mining machine begins to cut coal, the methane concentrations at the face can rise and fall rapidly. If the methanometer response time is slow, the actual concentrations may be higher than the indicated readings. A monitor must not only measure the methane concentration accurately but must also respond quickly to changes in concentration in order to indicate a potentially hazardous condition. However, there are no criteria for measuring instrument response times.

Procedures for measuring such times were developed for use underground and in the laboratory. Work by Taylor et al. (2002) measured response times of three different catalytic heat of combustion type methanometers currently approved for underground use in the US. Using 2.5% calibration gas, they measured times ranging from 29 to 40 sec for a 90% response. The difference in response times between these instruments was attributed primarily to differences in the designs of the sensor heads. In these tests, gas was applied to the sensor head via a calibration cup which is typically used underground to calibrate the sensors. However, this arrangement altered the normal flow of gas around and through the sensor head. Subsequent analyses by Taylor et al. (2004) used a test box to more accurately measure response times without the use of the calibration cup (Fig. 2). The test box provided a way to expose the sensor heads to gas in a way that more closely simulated underground flow conditions on a mining machine. Response times for the three monitors mentioned in the earlier study varied from 23 to 29 sec for a 90% response to a 2.5% methane mixture. Although the researchers found that dust cap and flame arrester design did impact response time, no attempts were made to optimize their designs.

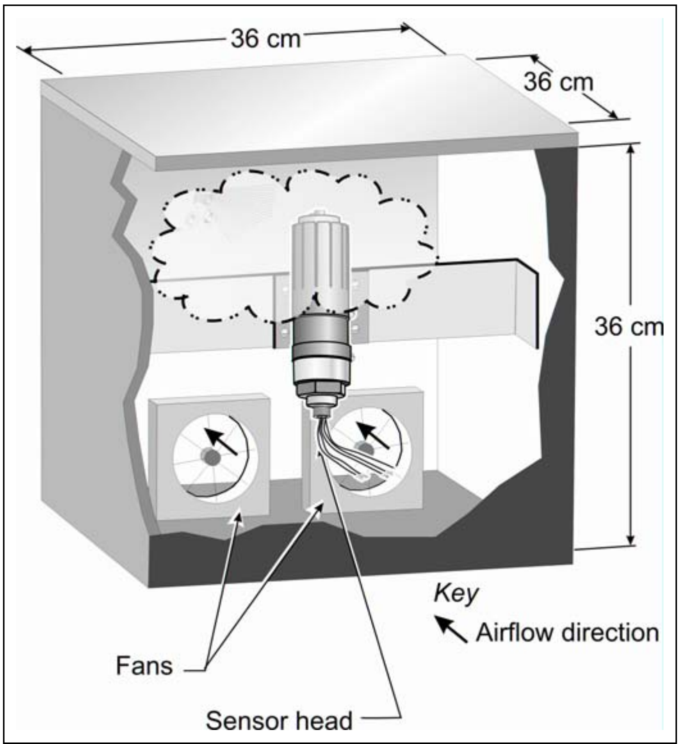

Figure 2. Test box for determining response times (Taylor et al. 2004)

3. NIOSH RESEARCH IN FACE EMISSIONS MODELING

Variability in emissions on longwall faces can arise from changes in geologic conditions, changes in surface relief which can affect reservoir conditions, and changes in the mechanical behaviour of the overburden which can affect abutment pressures, fracture formations and permeabilities. Elevated methane levels can slow the cutting rate of the shearer or continuous miner to allow bleed-off of excess gas. One study noted more frequent methane-related delays when mining near the tailgate (Schatzel et al. 2006).

These delays increased in number as the face moved to a maximum distance away from a borehole exhausting in the gob. Other studies showed more delays due to elevated gas levels when mining from the headgate to the tailgate (Krog et al. 2006). Despite the apparent abundance of data concerning methane levels on longwall faces, little published data exists on their effects on continuous mining operations.

Prior monitoring studies directed at longwall face emissions have indicated that only a small portion of the overall methane emission and gas production is emitted at the mine face (Diamond & Garcia 1999). However, these emissions can be critical in terms of underground safety. High productivities can elevate methane emissions along the longwall face making it difficult to meet statutory limits on methane concentrations. The current industry trend towards larger panels, particularly towards increasing face lengths, can present additional challenges for longwall face ventilation (Balusu et al. 2006, Schatzel et al. 2006). These include increased resistance to airflow and decreased velocities at the tailgate leading to potential methane layering. Also, wider panels can lead to increased methane emissions from the exposed face and from the cut coal lying on the face conveyor (Krog et al. 2006).

A methodology developed by Diamond & Garcia (1999) predicted future methane emissions for two future 300 m faces based on emissions measured on current 230 m wide faces. Curves were fit to the actual emission data and then extrapolated to the 300 m face widths to predict methane emission rates on these longer faces. The data showed that the two faces would likely experience significantly different emission rate consequences in response to increasing their panel widths. Variabilities in mine design and methane control practices between the two sites were the primary causes of the different predicted methane emissions rates.

Other researchers produced similar empirical models of methane emissions, although some caution was necessary in extrapolating these results to other sites. A data set was analyzed using two independent methods and many of the findings were consistent (Krog et al. 2006, Schatzel et al. 2006). Krog calculated methane emissions for a 480 m longwall face. These emissions were based on computed constants associated with specific methane sources (shearer, face conveyor, belt, background emissions from the coal face and background emissions from the adjoining ribs in the intake gateroads) and a zero time delay "idealized" longwall face pass of the shearer. Schatzel predicted lower face emission rates for a face length of 490 m by incorporating production delays and average emission rates in his calculations.

4. NIOSH RESEARCH ON ENGINEERING CONTROLS

Much of the work of the US Bureau of Mines and the National Institute for Occupational Safety and Health dealt with improving the flow of fresh air to the cutting faces on longwall and room-and-pillar mining systems. Historical overviews of ventilation designs for underground coal mining are given in Reed & Taylor (2007) and Kissell (2006).

In addition to ventilation airflow, water sprays control methane levels on continuous and longwall mining operations by increasing the turbulence needed to improve mixing and dilution of the gas. Work conducted in a full-scale continuous miner test gallery showed the effects of water sprays on methane levels measured at the face (Taylor & Zimmer 2001). Four separate spray systems were tested. This included a top spray manifold above the cutter head with 10 sprays oriented toward the face, a similar manifold with 10 sprays oriented 30 degrees to the return side of the machine, a side spray manifold consisting of 4 sprays mounted vertically on the upwind side of the cutter head, and an underboom spray manifold consisting of 4 sprays mounted beneath the cutter boom.

The results showed that the underboom spray manifold produced lower methane concentrations when used with the top sprays oriented toward the face, as opposed to 30 degrees to the return side.

When operating the side spray manifold, the 30 degree-oriented sprays produced lower methane levels than the top sprays oriented toward the face. This was attributed to the angled top sprays providing improved removal of the gas from the face area. When used with the underboom and side spray manifolds, no differences in average face gas concentrations were apparent with use of either top spray manifold.

A series of laboratory evaluations examined the selection, placement, and operation of water sprays to control gas levels around a continuous mining machine (Goodman et al. 2006). This work evaluated the impacts of three different water spray configurations. The first was the standard spray system consisting of 24 sprays positioned above, below, and along the sides of the cutter head (Fig. 3). The second configuration added two external sprays approximately 4 m from the cutter head along the body of the continuous miner and on top of the cutting boom, while the third placed six additional sprays under the cutting boom. Using sulfur hexafluoride as a surrogate for methane gas, concentrations were measured on the left and right sides of the cutter head. The sprays design incorporating the standard spray system plus the 4 external sprays provided the best control of face gas levels by increasing air velocity around the cutter head. This study did not recommend use of the underboom sprays because they increased gas concentrations.

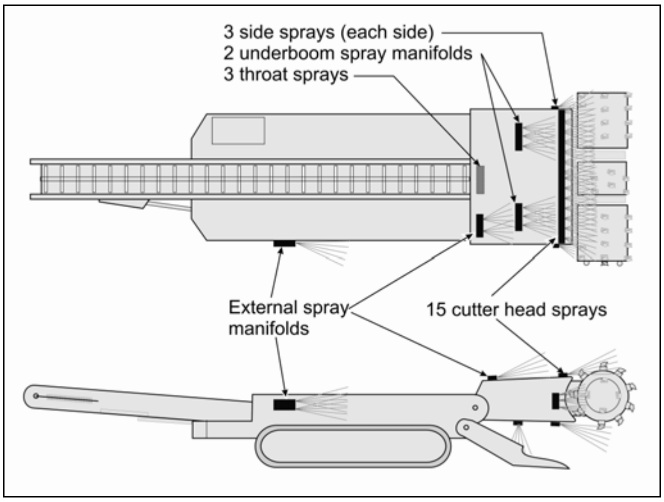

Figure 3. Water spray systems used in testing

Water sprays on a longwall shearer are typically oriented in a “shearer-clearer” pattern using a combination of low pressure (410 kPa) sprays on the cutting drums and higher pressure (1030 kPa) sprays on the shearer body. This system, originally designed to control respirable dust, was improved with the addition of two sprays on the headgate splitter arm and three sprays on the tailgate splitter arms. These sprays forced the airflow toward the face side of the shearer body and then toward the downwind side of each cutting drum, flushing out methane accumulating in these areas (Kissell 2006).

5. NIOSH RESEARCH IN COAL BED AND GOB DEGASIFICATION

Should increases in ventilation or changes in operational parameters be unable to control face gas levels, methane drainage remains the most viable option for mine operators. Most of the methane drainage applications in the United States have involved horizontal in-seam boreholes and vertical gob gas ventholes (GGV). Cross-measure boreholes have had limited application in the United States, their use being more widespread in European operations. The history of methane drainage is quite extensive and has been well-documented in the literature (Diamond 1994, Thakur 2004).

In-seam boreholes drilled from underground workings have been used to remove coalbed methane from both longwall faces and gateroad development entries. This technique has been applied widely in the US coal mining industry and has the advantage of controlling methane emissions in both areas. Successful application of this drainage technology still involves keeping the drilling progress sufficiently ahead of mining activities such that the coal seam has adequate time to degas prior to extraction.

In-seam boreholes can be oriented roughly parallel to the longwall face or can be directionally drilled perpendicular to the mine face (Fig. 4B). The impacts of borehole pattern and completion parameters were modeled (Karacan et al. 2007). This work showed that the most effective pattern for draining methane from a longwall panel was the tri-lateral arrangement that created three branches off of a single borehole. The greatest reductions in methane emissions were achieved by degasifying before and during panel extraction. In-seam holes can also be drilled in the longwall block parallel to the developing gateroads to capture gas from the longwall panel that would otherwise migrate to gateroads and require dilution by ventilation air (Diamond 1994). These wells act as shields preventing the migration of methane from the surrounding roadways into the development entries.

A reservoir model was developed to assess the impact of shielding boreholes on methane emissions rates during development of gateroad entries (Karacan 2007). The model included a three-entry headgate and tailgate layout. A number of operational, geologic, and reservoir factors were included in the model to assess their impacts on emissions and on the ventilation flow required to control those emissions. The results showed that degasification using shielding boreholes decreased emissions 25% compared to the unshielded case. Shielding wells located close to the gateroads and operated for longer times were more effective in reducing methane inflows. Another study used an artificial neural network to design a coal bed degasification system using site- and mine-specific parameters (Karacan 2008).

Vertical gob gas ventholes are drilled over longwall panels to drain gas from the gob as the panel is extracted (Fig. 4A). The use of GGV's is widespread in the US longwall coal mining industry and NIOSH has conducted considerable research to optimize their performances (Diamond 1994). For instance, increasing GGV diameter resulted in more methane production, although gas concentration could be diluted by the inclusion of more mine air. Locating the bottom of the GGV in the cave zone of the gob also removed mine ventilation air. Karacan et al. (2005) studied the effects of increasing face length on GGV performance. The performance and configuration of GGV's can vary widely although these methane drainage boreholes generally undergo a peak production period shortly after undermining. The methane flow rate then declines and reaches a long production tail at a lower rate. The conventional design of GGV's includes surface exhausters that produce a negative pressure on the boreholes to enhance coalbed gas production. It is a widely-held industry belief that these methane drainage boreholes reduce emission rates at longwall faces, although no clear cut quantification of this effect has been documented.

The use of coalbed methane drainage in room-and-pillar operations (mains and sub-mains) is less common than in longwall mining operations. Possible benefits of methane drainage include reduced ventilation costs, a modest increase in coal reserves, and reduced cost due to a reduction in methane-related downtimes (Wang & Mutmansky 1999). However, methane drainage appears to be economic for a room-and-pillar operation only if the methane content of the coal is at least 19 m^3/tonne. As a comparison, the economic limit for methane drainage on a longwall operation is 12

m^3/tonne. Such estimates, however, made no allowances for variations in permeability, porosity, or other factors impacting gas production.

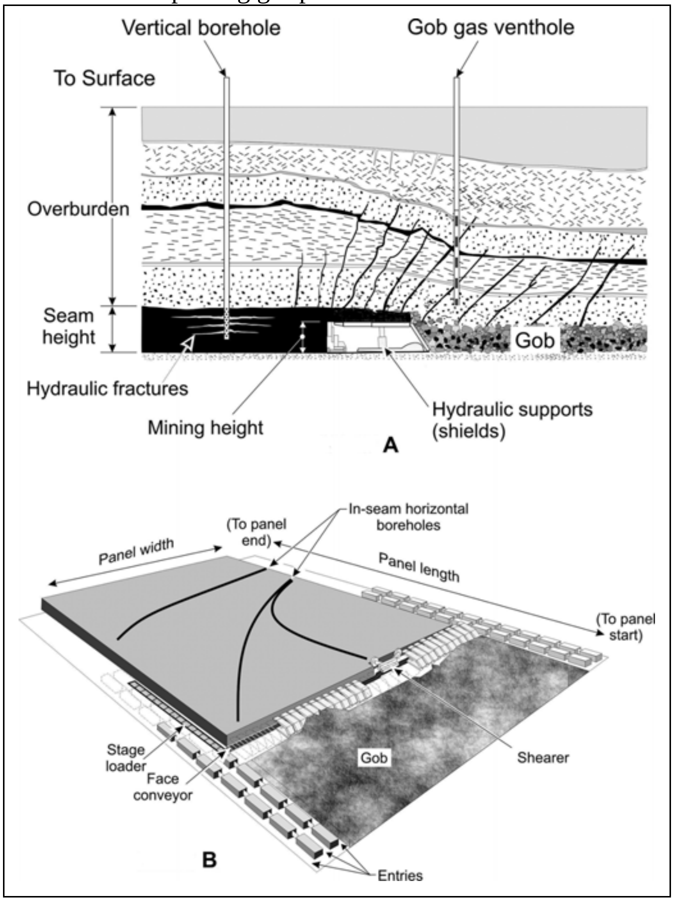

Figure 4. Schematic representation of longwall mining environment and commonly used degasification borehole types (Karacan 2008)

SUMMARY

Available methane control systems have been challenged by recent developments in longwall and room-and-pillar mining systems including increases in panel dimensions, increased advance rates, and increased working depths. Due to the potentially violent nature of any underground explosion or ignition, control and reduction of methane emissions into the mine environment in necessary for continued worker safety.

To ensure the safety of the nation's underground mine workers, methanometers are placed on mining equipment to monitor gas levels during the shift. The protective capability of a methanometer depends upon the accuracy of that device and the response time as methane levels change during mining. NIOSH examined the response times of three methane monitors approved for underground use. Methane gas was initially introduced to each methanometer via a calibration cup attached to the sensor head, a procedure found to provide an unrealistic assessment of response times.

Subsequent testing introduced the methane gas into a large test box, a configuration that was determined to more accurately mimic underground conditions.

Past work showed that only a small percentage of the methane originated at the face area, with most of the gas coming from the gob area. NIOSH research identified those areas where methane control could be critical for longwall operations, i.e. mining towards the tailgate especially at a maximal distance from a gob gas venthole. Models have been developed to predict both current and future methane emissions on longwalls. Some of the models were used to estimate emissions for wider longwall faces, a path that many coal operators are taking.

Engineering controls have been extensively researched by NIOSH to control methane accumulations while mining. These have included the improved application of ventilation airflow to dilute and remove harmful gas levels and the development of more effective water sprays systems to increase mixing and turbulence. Such spray systems include the shearer clearer for longwall operations and the use of top sprays, external sprays, and underboom sprays on continuous mining equipment.

NIOSH has a long history of work in methane degasification involving the use of horizontal in-seam boreholes and vertical gob gas ventholes. Reservoir models have been used to assess the impacts of shielding boreholes on gateroad developments and to evaluate the effects of reservoir parameters on emissions levels. This work has modelled the impacts of borehole pattern and design and the effects of increasing face length on gob gas venthole performance.

REFERENCES

Balusu R., Tuffs N. & White D. 2006: Surface Goaf Gas Drainage Strategies or Highly Gassy Longwall Mines. J. Mine Vent. Society of South Africa 59(3), pp. 78−84.

Diamond W.P. 1994: Methane Control for Underground Coal Mines. U.S. Dept. of Interior, U.S. Bureau of Mines, Information Circular, No. 9395.

Diamond W.P. & Garcia F. 1999: Analysis and Prediction of Longwall Methane Emissions: A Case Study in the Pocahontas No. 3 Coalbed. VA, U.S. DHHS/CDC/NIOSH, Report of Investigations, No. 9649.

Goodman G.V.R., Beck T.W. & Pollock D.E. 2006: The Effects of Water Spray Placement for Controlling Respirable Dust and Face Methane Concentrations. J. Mine Vent. Society of South Africa 20(2), pp. 56−63.

Karacan C.Ö., Diamond W.P., Esterhuizen G.S. & Schatzel S.J. 2005: Numerical Analysis of the Impact of Longwall Panel Width on Methane Emissions and Performance of Gob Gas Ventholes. Proceedings, Intl. Coalbed Methane Symposium, Paper 0505, Tuscaloosa, AL, May 18−19.

Karacan C.Ö. 2007: Development and Application of Reservoir Models and Artificial Neural Networks for Optimizing Ventilation Air Requirements in Development Mining of Coal Seams. Intl. J. Coal Geology 72, pp. 221−239.

Karacan C.Ö., Diamond W.P. & Schatzel S.J. 2007: Numerical Analysis of the Influence of In-seam Horizontal Methane Drainage Boreholes on Longwall Face Emission Rates. Intl. J. Coal Geology 72, pp. 15−32.

Karacan C.Ö. 2008: Degasification System Selection for U.S. Longwall Mines Using an Expert Classification System. Computers and Geosciences (to be published).

Kissell F.N. (ed.) 2006: Handbook for Methane Control in Mining. DHHS/CDC/NIOSH, Information Circular, No. 9486.

Krog R.B., Schatzel S.J., Garcia F. & Marshall J.K. 2006: Predicting Methane Emissions from Longer Longwall Faces by Analysis of Emission Contributors. In J.M. Mutmansky & R.V. Ramani (eds.), Proceedings, 11th US/NA Mine Ventilation Symposium, Penn State University, University Park, PA, June 5−7, Littleton, CO, Society for Mining, Metallurgy and Exploration.

Reed W.R. & Taylor C.D. 2007: Development of Coal Mine Face Ventilation Systems During the 20th Century. Mining Engineering 59(8), pp. 40−51.

Schatzel S.J., Krog R.B., Garcia F. & Marshall J.K. 2006: Prediction of Longwall Methane Emissions and the Associated Consequences of Increasing Longwall Face Lengths: A Case Study in the Pittsburgh Coalbed.

In J.M. Mutmansky & R.V. Ramani (eds.), Proceedings, 11th US/NA Mine Ventilation Symposium, Penn State University, University Park, PA, June 5−7. Littleton, CO, Society for Mining, Metallurgy and Exploration.

Taylor C.D. & Zimmer J.A. 2001: Effects of Water Sprays and Scrubber Exhaust on Face Methane Concentrations. In S. Waselewski (ed.), Proceedings, 7th Intl. Mine Ventilation Congress, Krakow, Poland, June 17−2, Krakow 2001, EMAG.

Taylor C.D., Chilton J.E. & Mal T. 2002: Evaluating Performance Characteristics of Machine-mounted Methane Monitors by Measuring Response Time. In E. DeSouza (ed.), Proceedings, 9th US/NA Mine Ventilation Symposium, Queens University, Kingston, ON, Canada, June 8−12, Lisse, A.A. Balkema.

Taylor C.D., Chilton J.E. & Zimmer J.A. 2004: Use of a Test Box to Measure Response Times for Machine-Mounted Monitors. In R. Ganguli & S. Bandopadhyay (eds.), Proceedings, 10th US/NA Mine Ventilation Symposium, Anchorage, Alaska, May 16−19. Littleton, CO, Society for Mining, Metallurgy and Exploration.

Thakur P.C. 2004: Coalbed Methane Drainage: The Past, Present and Future. In R. Ganguli & S. Bandopadhyay (eds.), Proceedings, 10th US/NA Mine Ventilation Symposium, Anchorage, Alaska, May 16−19. Littleton, CO, Society for Mining, Metallurgy and Exploration.

Wang Y. & Mutmansky J.M. 1999: Economic Analysis of Coalbed Methane Drainage Systems for Room-and-Pillar Operations. In J.C. Tien (ed.), Proceedings, 8th U.S. Mine Ventilation Symposium, University of Missouri-Rolla, Rolla, MO, June 11−17. Littleton, CO, Society for Mining, Metallurgy and Exploration.