11th U.S./North American Mine Ventilation Symposium 2006 – Mutmansky & Ramani (eds)
© 2006 Taylor & Francis Group, London, ISBN 0-415-40148-8

Prediction of longwall methane emissions and the associated consequences of increasing longwall face lengths: A case study in the Pittsburgh Coalbed

S.J. Schatzel, R.B. Krog, F. Garcia & J.K. Marshall
U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA, USA

J. Trackemas
Pennsylvania Services Corporation, Foundation Coal Company, Waynesburg, PA, USA

ABSTRACT: In an effort to increase productivity, many longwall mining operations in the U.S. have continually increased face lengths. Unfortunately, the mining of larger panels may increase methane emissions. The National Institute for Occupational Safety and Health (NIOSH) conducted a mine safety research study to characterize and quantify the methane emissions resulting from increasing face lengths in the Pittsburgh Coalbed. The goal of this research effort was to provide the mine operator with a method to predict the increase in methane emissions from the longer faces for incorporation of additional methane control capacity into the mine planning process, if necessary. Based on measured methane emission rates of 0.066 m^3/s (140 cfm) for a 315 m (1032 ft) face, projected longwall face methane emission rates were 0.090 m^3/s (191 cfm) for a 366 m (1200 ft) face, 0.106 m^3/s (225 cfm) for a 426 m (1400 ft) face, and 0.124 m^3/s (263 cfm) 488 m (1600 ft) face.

1 INTRODUCTION

Continuous enhancements in longwall mining equipment have significantly improved face advance rates. This increasing longwall advance rate has generally outpaced the continuous miner development section advance rate. One potential solution is to decrease the relative amount of development mining required by increasing the size of longwall panels, in particular face lengths. However, increases in longwall face length can create problems such as increased cumulative face methane emissions and increased potential for methane-related production delays (Krog et al. 2006). This may be further exacerbated by the complex airflow movements along the face itself. Although airflow movement along the longwall face is generally assumed to be linear, evidence of exchanges between face and gob atmospheres have been noted (Balusu et al. 2001, Wendt & Balusu 2001). Other researchers have suggested an increased level of opportunity for air exchanges between face and gob regions result from resistant roof units and associated void spaces behind the longwall face (Noack 1998, Balusu et al. 2001, Wendt & Balusu 2001). This hypothesis suggests that under certain roof conditions, increased longwall face lengths could also increase the void space behind the face. This increase in void space in the face and gob areas represents an increase in permeability. Most prior research regarding gob permeability addresses airflows in the bleeder entries between mined-out panels (Mucho et al. 2000) or characterizations within the longwall gob (Sing & Kendorski 1981, Brunner 1985, Karacan et al. 2005) and not the near face locations.

This research effort was designed to address issues in predicting and configuring adequate longwall face ventilation when face lengths are increased. One goal of this study was to predict the magnitude of the increase in the face methane emission rates due to an increase in face length. A second goal was to characterize air and methane movements along the face, as well as the influence of the mining direction of the shearer and production delays, including methane delays, on face emission rates. With respect to the methane delays, an effort was made to identify any potential patterns or causes relative to how, when, and where they occur. A final goal was to learn how significant changes in the geology, mining practices (e.g. methane drainage) and mining conditions might affect methane emission rates. Achieving the goals of the study would increase the industry's understanding of longwall face emissions and associated ventilation issues. Ultimately, the most important outcome sought in this research project was to enhance miner safety in the underground mining environment by reducing the frequency of hazardous accumulations of methane on longwall faces.

2 METHODOLOGY

2.1 *Study site*

The field site for this study was a longwall coal mine operating in the Pittsburgh Coalbed in southwestern Pennsylvania. The mine operated three continuous miner development units and one longwall system. The annual production from the mine is approximately 5.9 million t (6.5 million short tons) per year, of which 5.0 million t (5.5 million short tons) are produced from the longwall mining system. Coal thickness at the mine ranged from 2.0 m (6.5 ft) to 2.4 m (8.0 ft). The depth of cover in the study area ranged from 183 m (600 ft) in the headgate area to 244 m (800 ft) in the tailgate area. The dimensions of the study panel were 3250 m (10,650 ft) long by 315 m (1032 ft) wide (Fig. 1) (dimensions of the outlined coal block). The study began with 1250 m (4100 ft) of panel length remaining. This panel was the third panel mined in a longwall district containing five longwall panels. The longwall bleeder system was ventilated by the use of a centrifugal bleeder fan, and four vertical gob ventilation boreholes per panel placed at regularly spaced intervals of approximately 610 m (2000 ft) to provide additional methane control capacity. Four horizontal in-seam methane drainage boreholes were also present adjacent to the gateroads of the study panel.

2.2 *Experimental procedure*

The basic methodology for this study was first developed by Diamond and Garcia (1999) for a longwall face emissions investigation at two mines operating in the Pocahontas No. 3 Coalbed, VA. The goal of the Diamond and Garcia (1999) study was to predict methane emissions rates for 305 m (1000 ft) faces based on face emissions monitoring on a 229 m (750 ft) wide face at the VP-1 and VP-3 mines (Fig. 2). In that study, continuous methane emissions monitoring was conducted near the headgate and tailgate corners. The face was divided into three equal segments of about 76 m (250 ft). Average cumulative methane emissions data for each of the three segments were plotted as a function of face length. Curves were fit to the actual emission data and were then extrapolated to the 305 m (1000 ft) face widths to predict methane emission rates on the longer faces. The data showed that the two mines would likely experience significantly different emission rate consequences in response to increasing the face lengths by about 76 m (250 ft). This was due to variations in mine design and methane control practices between the two mine sites.

For this study in the Pittsburgh Coalbed, continuously recording methane monitors were installed along the 157 shields of the longwall face. The monitors were sampled at 5 sec. intervals, and 1-minute average methane concentrations were recorded by data loggers. Airflow measurements were made at various locations on the face multiple times per shift to provide ventilation airflow measurements for the calculation of emission rates based on the methane concentration data. A production time study consisting of shearer location on the face (recorded as shield numbers) and shearer mining direction (head-to-tail or tail-to-head) was also conducted throughout the three days of the face emissions monitoring. One shift was monitored on each of the three days of the study. The duration and cause of all production delays, the face position at the start and end of each shift, the presence of any discernable geologic discontinuities or conditions encountered along the face, and any other pertinent data or observations were also noted as part of the time study record.

To analyze the movement of methane emissions in the longwall ventilation airflow, the face was divided into four segments of equal length. Thus each

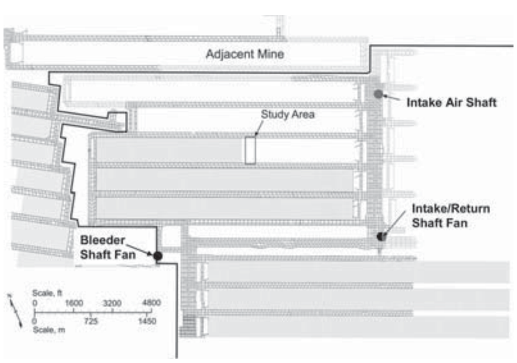


Figure 1. Longwall face emission study area.

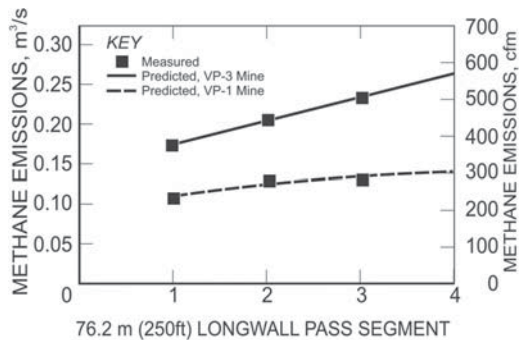


Figure 2. Prediction of methane emissions at greater longwall face lengths (Diamond & Garcia 1999).

face segment measured approximately 79 m (258 ft) (Fig. 3). Methane emission rates were determined for each face segment of each pass of the shearer using the associated methane concentration, ventilation airflow, and time study data. For this study, three continuously recording methane sensors were used for face methane monitoring. Since the principal focus of this study was longwall face ventilation and methane emissions, the decision was made to position the monitors away from the headgate and tailgate corners to avoid the inclusion of ventilation air in these areas which did not traverse the face. The methane sensors were installed at shields 20, 80, and 145 (Fig. 3). The distances from the headgate corner to each monitoring location were 35, 158, and 290 m (114, 517, and 953 ft) for the 315 m (1032 ft) face (Fig. 3).

To analyze the acquired methane emissions data, the longwall face segments were designated as 1, 2, 3, and 4, as numbered from the headgate for head-to-tail (H-T) passes, and were designated as 1a, 2a, 3a, and 4a, for tail-to-head (T-H) passes as numbered from the tailgate as shown in Figure 3. Average methane emission rates were computed for each of the face segments using simple algebraic formulas to determine the methane volume emitted, which was then divided by the time required to mine each face segment. Consequently, a total of four methane emission rates were computed for each pass of the longwall shearer in each direction. A sample face segment methane emission rate calculation is shown in Table 1. This sample shows methane emissions data from a shearer pass through face segment 3 with no delays. Methane emissions measured during the mining of this segment are determined as the difference in emission rates at two continuously recording methane sensors, while the shearer position for each minute of mining is shown relative to the longwall shields. From this data, average methane emission rates can be determined for each segment.

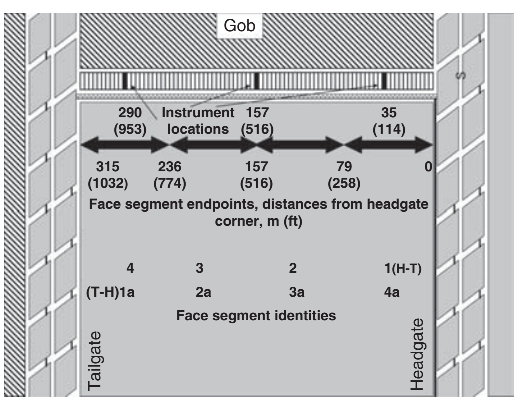


Figure 3. Pittsburgh Coalbed longwall face emission study site with instrument locations and face segment identities.

All three methane sensors were used in this analysis, with the nearest downstream methane sensor used to compute the methane emission quantities. The transit time for ventilation air to flow along the longwall face was determined, and the duration of airflow from the end of a face segment to the sensors ranged from 0 seconds to about 1 minute in computing methane emission quantities. This airflow transit time along the face was ignored in the computations for the following reasons: 1) even the longest transport time (one-minute) to a methane sensor is small compared to the time required for the shearer to mine the segment, 2) according to the protocol, the methane produced in the mining of the face segment was measured after the shearer actually passed the methane sensor to allow time for the instrument to respond to methane in the airstream, and 3) the recorded methanometer data were averaged over each minute of monitoring.

Due to the location of the recording methanometers (Fig. 3), face segments 1, 4, 1a, and 4a are actually shorter than the specified 79 m (258 ft) length. In segments 1 and 4a, all ventilation airflow passing across the segment reaches one or more of the methane sensors. For face segments 1a and 4, all of the ventilation airflow does not reach the sensors (Fig. 3). Consequently, for face segments 4 and 1a, some assumptions were made based on general trends in the methane emissions data to determine methane emission quantities when the shearer was on the tailgate side of the methane sensor located on shield 145 (Fig. 3). In applying this methodology, the following assumptions have been made to project methane emissions to longer faces: 1) the mine advance rate and the frequency of mining delays will occur at about the same rate; 2) face methane emissions are assumed to be constant within each segment; 3) all sources of methane emissions change at a constant rate with increased face length; and 4) the solutions are site specific for the Pittsburgh Coalbed, the ventilation configuration, and the methane drainage systems applied at the study mine site.

Table 1. Sample calculation of emissions data for face segment 3 acquired during day 1 of the face emissions study.

Time cutting face segment, h:min	Recorded shearer position, shield number	CH_4 emission rate at start (shield 80), (m^3/s)	CH_4 emission rate at end (shield 145), (m^3/s)	CH_4 emission during pass in face segment 3, (m^3/s)
20:39	88	0.021	0.079	0.059
20:40	–	0.021	0.099	0.078
20:41	–	0.021	0.099	0.078
20:42	–	0.021	0.099	0.078
20:43	116	0.021	0.099	0.078
20:44	120	0.041	0.099	0.058

3 RESULTS AND DISCUSSION

3.1 *Analysis of the methane emission data from the 315 m (1032 ft) longwall face*

On the study panel, belt air was used on the longwall face (Fig. 4). After the shearer completed a T-H pass, sumped in, and began an H-T pass, methane carried to the face from the belt line made up the great majority of the methane measured at the shield 20 methanometer. Under these circumstances, the data showed that methane emissions at the shield 20 location frequently exceeded those at the shield 80 location (i.e. non-linear airflow along the longwall face). Consequently, for analytical purposes, face emissions were assumed to be zero for the first 20 shields of an H-T pass (up to 35 m, 114 ft from the headgate corner). Although this may not be a totally accurate assumption, data analysis indicated that the level of methane emissions in this portion of the face was quite low, usually measured as between 0.0 and 0.021 m^3/s (0 to 44 cfm). This portion of the longwall panel is near the previously developed headgate entry, so there is a significant opportunity for the migration of methane out of this portion of the unmined solid coal block prior to mining.

The sums of gas emissions from the eight face segments for the H-T and T-H passes were normalized to match actual gas emission totals measured at the shield 145 methane emissions monitor. A total of 24 passes were analyzed and three of those passes were not complete data sets. No passes were eliminated from the data set due to production delays. A total of 27 methane-related delays were noted during the study: 4 on the first day, 11 on the second day, and 12 on the third day. Methane delays were typically of short duration, averaging about 7 minutes. Consequently, separation of data with methane delays to view only data showing uninterrupted passes was not possible because of the high percentage of passes affected by short duration methane delays.

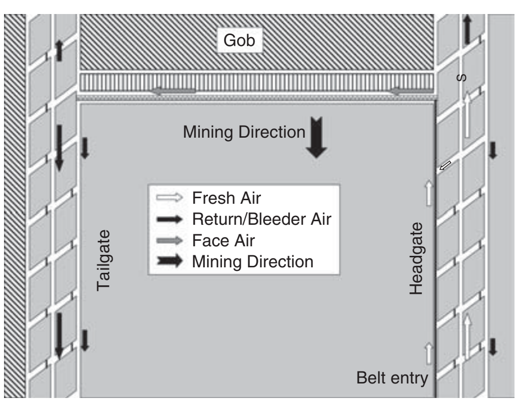


Figure 4. Ventilation configuration at study site.

The cumulative methane emission rates for the face segments for each of the three days of the study are shown in Figure 5 and Table 2. Face methane emission rates were consistently higher by about 41% in the H-T passes than in the T-H passes, in part because of the longwall face mining sequence which produced a much longer "wedge" cut towards the tailgate than towards the headgate entry and the slower shearer cutting rate in the T-H passes due to panline loading. Methane emissions were lowest on day 2, [0.042 m^3/s (88 cfm)] of the methane emission monitoring study and highest [0.061 m^3/s (129 cfm)] on day 3 at shield 145. One contributing factor to the changes in methane emission rates over the course of the study is thought to be the proximity of gob vent boreholes (GVB's) located near the tailgate side of the panel. The study area was approaching the maximum distance between gob vent boreholes (GVB's), where the next borehole would be intercepted two days after the study was completed. This may account for a general increase in

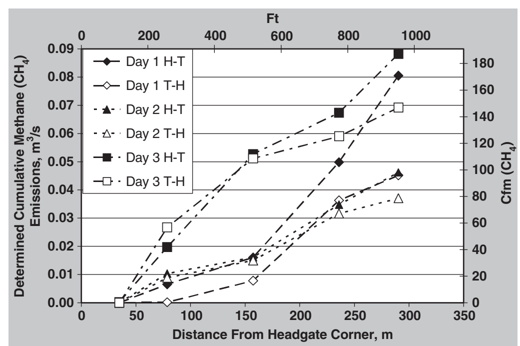


Figure 5. Cumulative longwall face methane emissions for the three days of monitoring. Showing the face segments endpoints.

Table 2. Cumulative face segment emission rates determined for each day of study.

Face segments, H-T	Day 1 values m^3/s (cfm)	Day 2 values m^3/s (cfm)	Day 3 values m^3/s (cfm)
1	0.007 (14)	0.010 (22)	0.020 (42)
2	0.016 (34)	0.016 (34)	0.053 (112)
3	0.050 (106)	0.035 (74)	0.067 (143)
4	0.081 (171)	0.046 (98)	0.088 (187)
Face setments, T-H			
1a	0.045 (96)	0.037 (78)	0.069 (147)
2a	0.036 (77)	0.032 (67)	0.059 (125)
3a	0.008 (17)	0.015 (32)	0.051 (109)
4a	0.000 (0)	0.009 (19)	0.027 (57)

methane concentrations prior to the next GVB coming on line, GVB 46-4 (Fig. 6).

The measured average daily methane emission rates varied from about 0.046 m^3/s (98 cfm) to about 0.088 m^3/s (187 cfm) on head-to-tail passes over the three days of the study (Fig. 5) (Table 2). Production delays due to increasing methane concentration were most common when the shearer was near the tailgate side of the longwall face of the H-T pass, but began occurring with increasing frequency at locations nearer the headgate side of the face as the study progressed over the three days. An analysis of methane emissions from individual face segments (Table 3) suggests potential causes of this behavior.

Average face methane emissions rates were calculated for each of the four face segments and each pass direction. These values varied during each pass and varied over successive days of the study. This variation in behavior can be viewed more clearly in Figure 7, which shows the average methane emissions from each segment alone (H-T and T-H combined data) during the three days of monitoring (Table 3). Figure 7 shows that the methane emissions produced during passes on day 1 were relatively low [from 0.003 to 0.009 m^3/s (7 to 18 cfm)] in the segments nearest to the headgate (1, 2, 3a, 4a). Emissions increased significantly in segments 3 and 2a [0.031 m^3/s (66 cfm)], and diminished somewhat from that level toward the tailgate in segments 4 and 1a. On day 2, methane emission rates in the near headgate segments 1 and 4a were higher than on day 1 [0.010 m^3/s (20 cfm)], and then decreased in the next segments, 2 and 3a [0.006 m^3/s (13 cfm)]. Similar to day 1, methane emissions increased in face segments 3 and 2a [0.018 m^3/s (37 cfm)] and then decreased slightly in the face segments towards the tailgate, i.e. face segments 4 and 1a [0.008 m^3/s (18 cfm)]. On day 3, methane emissions were much higher [0.023 m^3/s (49 cfm)] near the headgate face segments 1 and 4a than during the prior two days of the study (Table 3). The methane emissions rate increased in the next face segments [0.029 m^3/s (61 cfm)] 2 and 3a, but then decreased significantly in face segments 3 and 2a [0.011 m^3/s (24 cfm)], with a slight increase [0.023 m^3/s (49 cfm)] in the tailgate segment face segments 4 and 1a (Fig. 7).

Methane drainage via horizontal boreholes near the face emission study area may have contributed to the variable methane emissions characteristics observed on the face. Two horizontal boreholes produced gas from the Pittsburgh Coalbed on the longwall panel near the study area. One hole was drilled on each side of the panel, and the holes were oriented parallel to the gateroad entries, about 30 m (98 ft) from the respective gateroads (Fig. 6). The holes were drilled towards the advancing face, and terminated in the study area. Prior to interception by mining, the holes were filled with water.

On day 2 of the study, the presence of a horizontal borehole on the face was noted near the tailgate side of the panel at shield 140. On day 3 of the study, the interception of the horizontal borehole near the headgate at shield 23 was observed. It is likely that coalbed

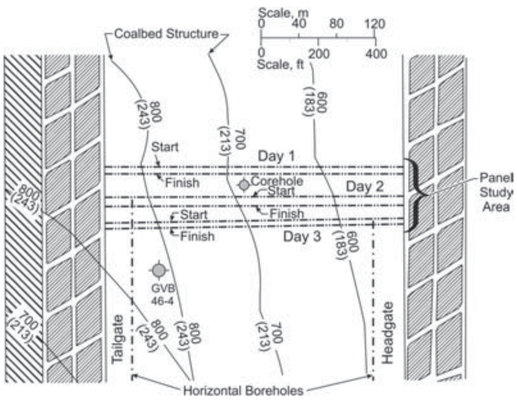


Figure 6. Actual portions of the study panel monitored for face methane emissions and associated methane drainage borehole locations.

Table 3. Face segment emission rate data shown for combined averaged H-T, T-H passes.

Face segments	Day 1 m^3/s (cfm)	Day 2 m^3/s (cfm)	Day 3 m^3/s (cfm)
1, 4a	0.003 (7)	0.010 (20)	0.023 (49)
2, 3a	0.009 (18)	0.006 (13)	0.029 (61)
3, 2a	0.031 (66)	0.018 (37)	0.011 (24)
4, 4a	0.020 (42)	0.008 (18)	0.016 (33)

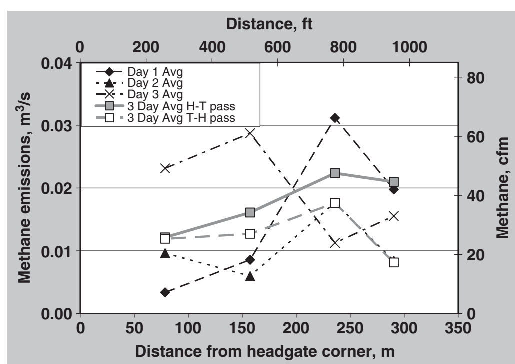


Figure 7. Average methane emission rates for each day of study determined for each face segment (the zero emission value assumed for the start of segment 1 and the end of segment 4a have been omitted).

methane production from the first borehole encountered near shield 140 on the tailgate side of the face had decreased the methane content of the Pittsburgh Coalbed in the vicinity of the borehole. Consequently, after the borehole was intercepted on day 2 of the study, methane emissions dropped towards the tailgate side, as shown by the comparison of face segments 4 and 1a on day 1 [0.020 m^3/s (42 cfm)] versus those on day 2 [0.008 m^3/s (18 cfm)] (Fig. 7). A similar drop in methane emission rates was not observed in face segments near the head gate from day 2 and day 3 when the borehole was intercepted near shield 23 (Table 3). It is not known if methane emissions would have diminished in the region of face segments 1 and 4a if the study had been continued for another day. Not all of the horizontal boreholes have the same time to produce gas prior to interception by longwall mining.

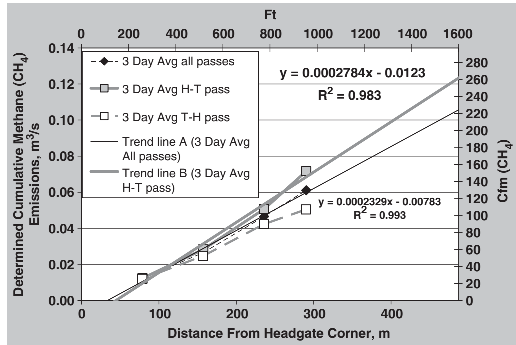


Figure 8. Methane emission prediction curves for the Pittsburgh Coalbed; trend line A based on average emission data; trend line B based on H-T pass emission data.

Production delays also affected face methane emission rates. Production delays, including those due to high methane emissions result in lower calculated pass segment methane emission rates because the time to complete the pass segment increases while the longwall face equipment is idle. Therefore, the increased number of methane-related production delays on day 3, and to a lesser extent on day 2, resulted in lower average methane emission rates on some individual pass segments, particularly on tailgate side face segments 4 and 1a (Fig. 7). Although day 3 of the study produced the highest cumulative methane emission rates for complete passes, these values would have been even higher had the methane-related delays not occurred, which resulted in reduced average emission rates on those individual pass segments.

3.2 *Predicting methane emission rates for longer longwall faces in the Pittsburgh Coalbed*

Graphs of the cumulative measured average methane emission rates for the 315 m (1032 ft) panel face segments in both the H-T and T-H directions are shown in Figure 8. From these data, two least-squares linear regression curves were calculated to predict methane emissions for longer face lengths of 366 m (1200 ft), 426 m, (1400 ft) and 488 m (1600 ft) in the Pittsburgh Coalbed. To create trend line A, all H-T and T-H passes were averaged and then an overall average emission pass plot was created. Trend line A was fit to this overall average emission pass data (Fig. 8). Trend line A predicts face emission rates of 0.077 m^3/s (163 cfm), 0.091 m^3/s (193 cfm), and 0.106 m^3/s (225 cfm), for face lengths of 366 m (1200 ft), 426 m, (1400 ft) and 488 m (1600 ft), respectively (Table 4). The equation for trend line A is given (in metric units) and the R^2 value of the curve fit to the data is 0.993. It should be noted that the emission rate for a 315 m (1032 ft) face is based on a projection of the cumulative emissions data from the face segments projected from shield 145 to shield 157 or 290 m (953 ft) from the headgate corner using data from all of the longwall passes. Trend line B was fit to the H-T passes only (Fig. 8). Since most of the delays occurred and higher face methane emission rates occurred on the H-T passes, this plot may be more representative of problematic concentrations of face gas than trend line A, which includes the generally lower T-H pass face emission rate data (Fig. 8). Using trend line B, with an R^2 value of 0.983, to predict methane emissions on longer longwall faces for lengths of 366 m (1200 ft), 426 m, (1400 ft), and 488 m (1600 ft) yields 0.090 m^3/s (191 cfm), 0.106 m^3/s (225 cfm), and 0.124 m^3/s (263 cfm), respectively, as compared to the 0.066 m^3/s (140 cfm) value for the base 315 m (1032 ft) panel (Table 4).

4 SUMMARY AND CONCLUSIONS

It should be noted that the results of this study to predict longwall face methane emissions at increasing face lengths is site specific and includes all delays which occurred during the monitoring period. Due to the higher rate of face methane emissions measured during H-T passes, linear trend line B was fit to only the averaged H-T passes, and is considered a better predictor of hazardous methane emission conditions on longer faces at the study site than an analysis using all of the data. Using trend line B developed from the H-T pass data, longwall face lengths of 366 m (1200 ft), 426 m (1400 ft), and 488 m (1600 ft) were predicted with an R^2 value of 0.983. Using trend line B, the predicted face methane emissions represent increases of 36%, 61%, and 88% for 366 m (1200 ft), 426 m (1400 ft), and 488 m (1600 ft) faces respectively, as compared to the base 315 m (1032 ft) face.

This methodology allowed for the computation of a total of eight methane emission rates from head-to-tail

Table 4. Face methane emission predictions based on projections made from face segment methane emissions determinations.

Face segments	Distance from headgate corner m (ft)	Average 3 day pass combined H-T, T-H data m^3/s (cfm)	Average 3 day H-T passes only m^3/s (cfm)
1, 4a	79 (258)	0.012 (26)	0.012 (26)
2, 3a	157 (516)	0.026 (56)	0.028 (60)
3, 2a	236 (774)	0.047 (99)	0.051 (107)
4, 1a	290 (952)	0.061 (129)	0.072 (152)
projection	315 (1032)	0.066 (140)	0.075 (159)
projection	366 (1200)	0.077 (163)	0.090 (191)
projection	426 (1400)	0.091 (193)	0.106 (225)
projection	488 (1600)	0.106 (225)	0.124 (263)

(H-T) and tail to head (T-H) passes. Analysis of the monitoring data suggests that horizontal methane drainage boreholes appeared to be effective in reducing methane emissions from the face in the vicinity of the borehole near the tailgate. A similar borehole intercepted near the headgate on day 3 did not appear to reduce emissions, but a subsequent day of face emissions monitoring was not conducted that could have confirmed that boreholes impact. The data also showed evidence of non-linear airflows, i.e. interactions of the longwall face air with airflows behind the shields. This was evident where belt air, carrying methane from the transported cut coal, increased concentrations near the headgate, while lower methane concentrations were measured at the mid-face location. Methane delays were most frequent when the shearer was mining near the tailgate. Methane delays on the longwall face increased in number from the first to third day of the study as the longwall face reached the approximate maximum distance from the nearest operating gob vent borehole (GVB) prior to interception of the next GVB, two days after the completion of the study.

With the determination of multiple emission rates over the length of a longwall face, the described method provides insight into changing emissions rates along the face due to all influential factors. The authors suggest that for projected increased methane emissions on wider panels, the methodology described by Krog et al. (2006), using this same data set in a companion paper, represents a more rigorous analysis of the methane source components contributing to the projected increased methane emissions. Thus, this companion analysis provides additional insights on appropriate control measures to address the projected increases in methane emissions, although it should be noted that both are empirical in nature and site specific. The longwall face methane emission predictions made by Krog et al. (2006) using the same data set are of greater magnitude than predictions appearing in this report. The primary reasons for differing face emissions predictions are: 1) the predictions made by Krog et al. were for peak load conditions and the predictions appearing here are for averaged data, and 2) the predictions made by Krog et al. were for an "idealized" cut sequence with no delays where the methane predictions in this analysis included all production delays occurring in the data set.

Providing scientific predictions of the methane emission consequences of implementing mine design changes, such as increasing longwall panel face lengths, was the primary goal of this research effort. With these methane emission predictions, adequate engineering and administrative controls can be implemented in advance to ensure that the underground workforce is not exposed to potentially hazardous concentrations of methane. Mine designers and ventilation engineers have several options at their disposal to deal with the higher emissions associated with increased longwall face length, such as increasing face ventilation airflow, utilizing or increasing methane drainage capacity, and ventilation system changes, or as a last, reducing the mining rate on the longwall.

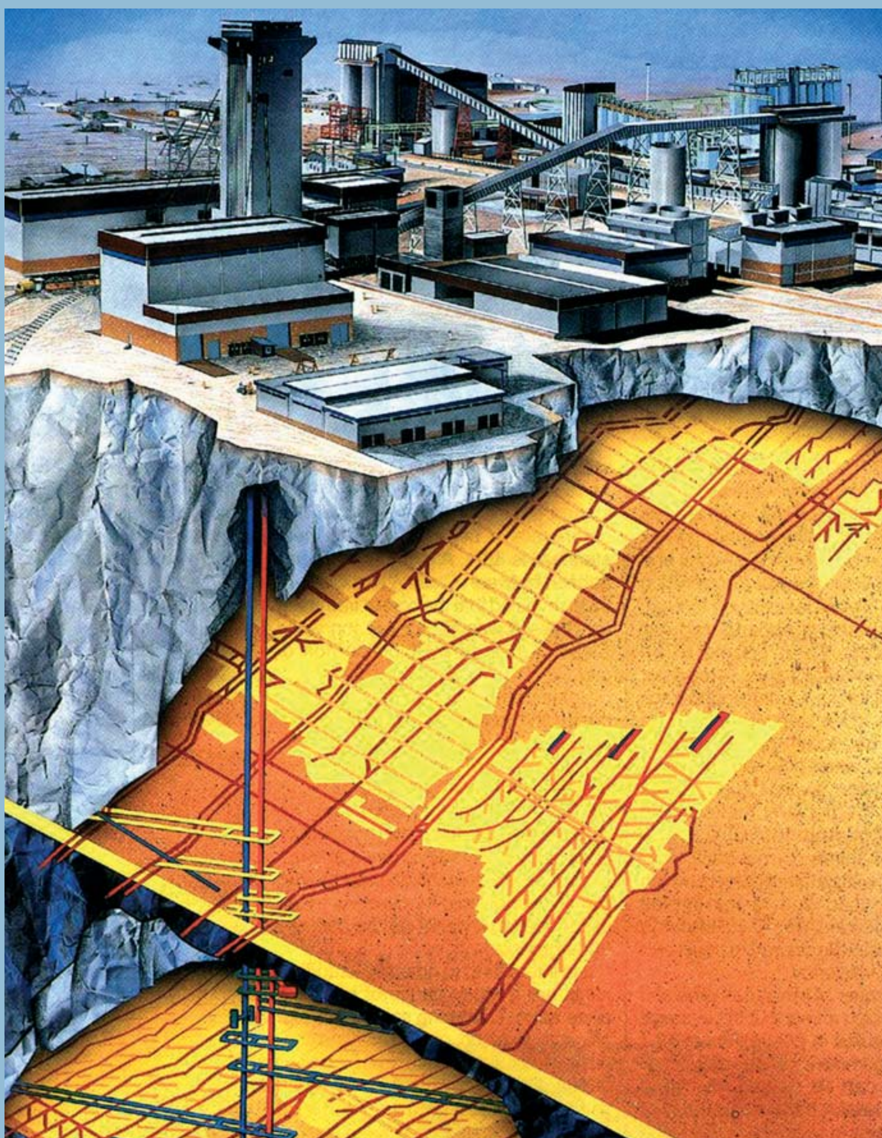
5 DISCLAIMER

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

REFERENCES

Balusu, R., Deguchi, G., Holland, R., Moreby, R., Xue, S., Wendt, M. & Mallet, C. 2001. Goaf gas flow mechanics and development of gas and sponcom control strategies at a highly gassy coal mine. Papers and presentations from the Australia-Japan Technology Exchange Workshop, Dec. 2–4, 2001, Hunter Valley.

Brunner, D.J. 1985. Ventilation Models for Longwall Gob Leakage Simulation. *Proceedings of 2nd US Mine Ventilation Symposium, September 23–25, Reno, NV*: 655–663.
Diamond, W.P. & Garcia, F. 1999. Analysis and prediction of longwall methane emissions: a case study in the Pocahontas No. 3 Coalbed, VA. NIOSH Report of Investigations, RI 9649.
Karacan, C.O., Diamond, W.P., Esterhuizen, E. & Schatzel, S.J. 2005. Numerical analysis of the impact of longwall panel width on methane emissions and gob gas ventholes. *Proceedings of the 2005 International Coalbed Methane Symposium, May 18–19, 2005, Tuscaloosa*.
Krog, R.B., Schatzel, S.J., Garcia, F. & Marshall, J.K. 2006. Predicting methane emissions from wider longwall panels by analysis of emission contributors. 11th U.S./North American Mine Ventilation Symposium, Pennsylvania State University, PA, USA, June 5–7, 2006, Rotterdam.
Mucho, T.P., Diamond, W.P., Garcia, F., Byars, J.D. & Cario, S.L. 2000. Implications of recent NIOSH tracer gas studies on bleeder and gob ventilation design. SME Annual Meeting and Exhibit, Feb. 28-Mar. 1, Salt Lake City.
Noack, K. 1998. Control of gas emissions in underground coal mines. *International Journal of Coal Geology* 35: 57–82.
Singh, M.M. & Kendorski, F.S. 1981. Strata disturbance prediction for mining beneath water and waste impoundments. In Peng (ed.), *Proceedings of the First Conference on Ground Control in Mining, July 27–29, Morgantown*: 76–89.
Wendt, M. & Balusu, R. 2001. CFD modeling of longwall goaf gas flow dynamics. *Proceedings of the Australia-Japan Technology Exchange Workshop, Dec. 2–4, 2001, Hunter Valley*.



11TH

U.S./NORTH AMERICAN MINE VENTILATION SYMPOSIUM

2006

Editors:
Jan M. Mutmansky
Raja V. Ramani