Evaluation of an exhaust face ventilation system for a 6.1-m (20-ft) extended cut using a scaled physical model

A.M. WALA, J.D. JACOB, L. RANGUBHOTLA AND T. WATKINS

A.M. Wala, member SME, **J.D. Jacob** and **L. Rangubhotla** are professor, associate professor and graduate student, respectively, with the University of Kentucky, Lexington, KY; **T. Watkins** is inspector with the U.S. Mines Safety and Health Administration, Pikeville, KY. Preprint number 03-148, presented at the SME Annual Meeting, Feb. 24-26, 2003, Cincinnati, OH. Revised manuscript received and accepted for publication March 2005. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Jan. 31, 2006.

Introduction

Current regulations dictate that coal mine face ventilation plans must be submitted to the U.S. Mine Safety and Health Administration (MSHA) by a coal mining company for evaluation and approval prior to implementation. Critical factors, such as the sweep of the face, worker exposure to dust and compliance with health and safety regulations pertaining to acceptable methane concentration levels, must be determined. To evaluate these factors properly, new and sophisticated engineering tools (methods) are needed. One possibility is an experimental method using full or scaled physical modeling. However, a full-scale model is prohibitively expensive. Another option is a computational fluid dynamics (CFD) model, which is relatively inexpensive and more flexible. However, this method still requires extensive validations to be used with confidence (Moloney and Lowndes, 1999; Wala et al., 2001; Wala et al., 2002).

CFD is a new and rapidly developing numerical technique by which complex fluid flow problems can be evaluated with a computer. This technique can be an attractive approach to predict, evaluate and design proper mine face ventilation systems. However, to develop assurance in the accuracy of CFD the verification between numerical and experimental results are required for validation purposes. During the last four and half years, such a validation study, funded by U.S. National Institute for Occupational Safety and Health (NIOSH) Grant #R01 CCR415822, was carried out by the Department of Mining Engineering, University of Kentucky (Wala et al., 2001; Wala et al., 2002).

As part of this project, the authors designed and developed a scaled physical model of face ventilation systems (Fig. 1). This model has been shown to be an acceptable tool for a scaled study of the face ventilation systems by a validation test performed in the full-scale testing facilities at the NIOSH Pittsburgh Research Center in June 2002.

Figure 2 shows measured two-dimensional flow distributions (velocity vectors) in the scaled model and a full-size testing gallery at NIOSH for comparison purposes. Both tests showed the same (unexpected) behavior. (Note that because the time scales are much larger in the full-scale scenario, fluctuations in the flow field did not provide as clear of a picture as in the model.) After this encouraging result, the authors are confident that scaled physical models can be used for validation of face ventilation plans and aid in the approval process.

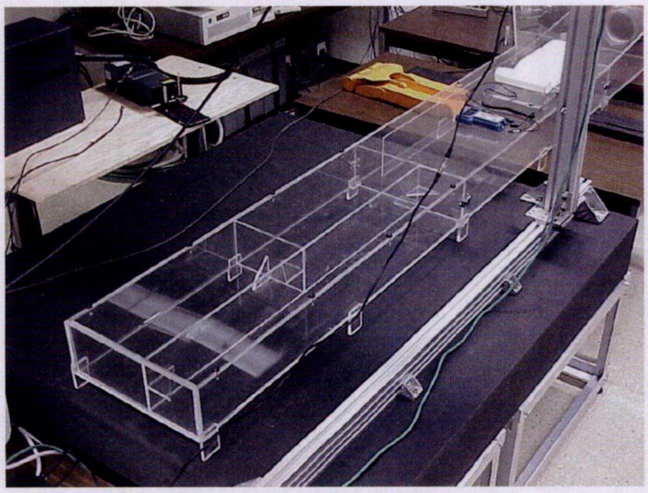
Need for face ventilation evaluation tools

Blowing face ventilation systems with scrubber-equipped continuous mining machine are commonly used in U.S. underground coal mines for extended cuts. This type of face ventilation system has been shown to be the most efficient if all components of the system are work-

Abstract

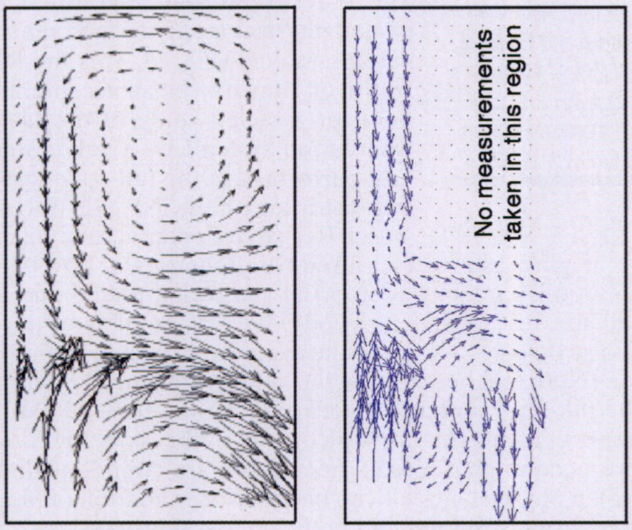
The face ventilation plans for extended-cut operations must be submitted by the coal mining company to the U.S. Mine Safety and Health Administration (MSHA) for evaluation and approval. The ability to perform an experimental and/or numerical study of the proposed ventilation arrangements could greatly enhance this evaluation process. These studies could provide a clear determination of the adequacy of the ventilation scheme in the face area and flag any possible problems. In this article, the authors present and discuss the data collected during an experimental study of face ventilation scenarios using a scaled physical model (1:15) and using an in-house designed and developed particle image velocimetry system. The face ventilation arrangements evaluated in this paper are typical of the plans submitted to MSHA for approval by Eastern Kentucky coal companies that utilize continuous mining machines not equipped with scrubbers or mechanical face ventilation enhancing devices.

FIGURE 1



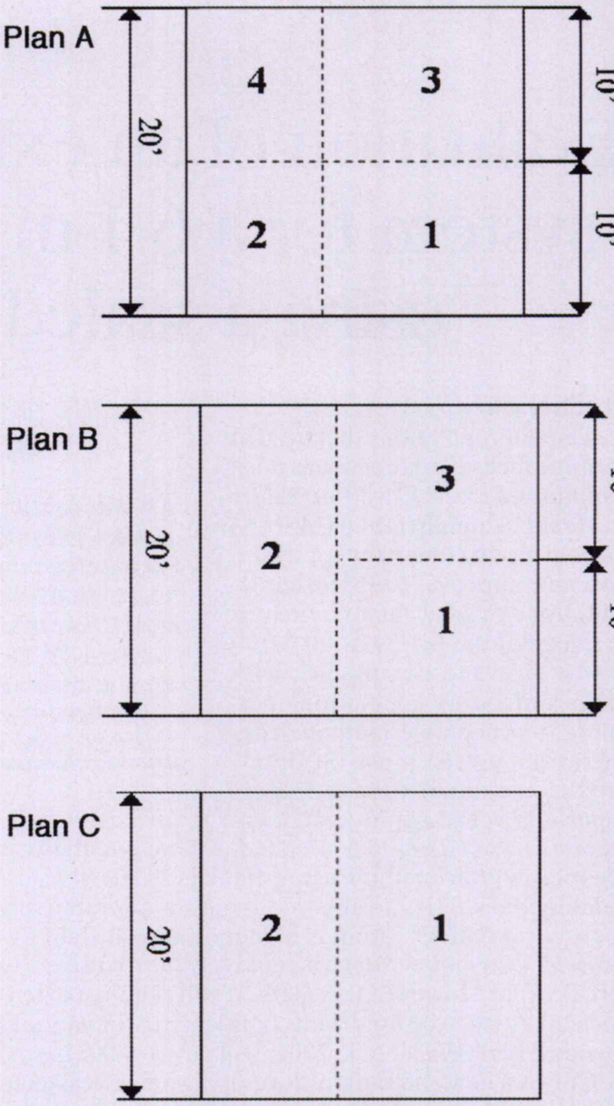
The physical model of the mine face area.

FIGURE 2



Comparison between scaled (model on left) and full-scale (NIOSH on right) flows.

FIGURE 3



Three typical exhaust face ventilation arrangements for 6.1-m (20-ft) deep cuts. Plan "A" is examined in the current study.

ing properly. However, in cases of scrubber failure or use of a continuous mining machine without scrubber or other mechanical face ventilation enhancing devices, the recommended blowing ventilation system must be replaced by the exhaust system.

Usually, when circumstances such as those described above occur, the typical plans for exhaust face ventilation are submitted to MSHA for approval (Fig. 3). The characteristic parameters of these plans are as follows:

- exhaust face ventilation systems;
- cut depths of 6.1 m (20 ft);
- the number of box (sump) cuts and slab cuts (cutting sequences) range from two to four;
- a line curtain air quantity of 2.1 m^3/s (4,300 cfm) and
- the first cut will always be on the curtain side.

By applying Plan A, the authors attempted to demonstrate in the experimental study how using scaled models equipped with a particle image velocimetry system can be useful in determining the flow distribution and evaluating control devices used for ventilation enhancements in the face area.

Scaled physical model for face ventilation plans validation

Description of the scaled physical model. A 1:15 scaled model of a 2.1-m- (7-ft-) high, 6.1-m- (20-ft-) wide mine face area was designed and built out of transparent Plexiglas (see Fig. 1). Scaling of the geometry was performed using dimensional analysis based on the Reynolds number

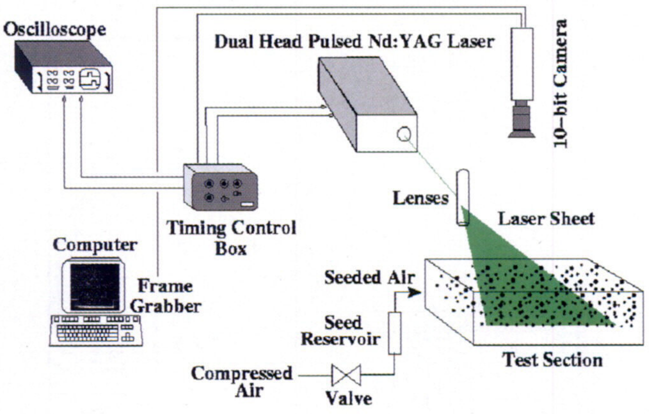
$$Re = UL/n \tag{1}$$

where

U and L are the velocity at the brattice line mouth and width of the inflow (distance between the brattice

FIGURE 4

Schematic of the integrated PIV system.



line and entry rib), respectively.

The model consists of three significant parts. First, the middle section, which represents an ordinary mining entry with a partition (brattice line), divides the entry into a narrow 0.6-m- (2-ft-) wide intake and a 5.5-m- (18-ft-) wide return airway. Second is the working section, which represents a face area, where movable Plexiglas walls can be used to replicate many different ventilation configurations such as box cut or slab cut arrangements with brattice setback distances varying from zero to 18.3 m (60 ft). Third is the intake/return section, where the ventilation system can be arranged as either blowing or exhausting by changing the fan location. During this particular study, the model was setup as an exhaust ventilation system with a setback distance of 6.1 m (20 ft) (Fig. 3).

Description of the particle image velocimetry system. The PIV technique was proposed for measurement of instantaneous velocity fields of the time dependent flows in the scaled model. PIV is an optical technique for measuring two velocity components over an extended two-dimensional area. To perform these measurements, tracer particles must be added to the flow field; highly reflective ~50-µm (270 mesh) talc particles were used in the experiments discussed herein. A laser-light sheet illuminates these particles twice within a short time-interval using a pulsed laser. The reflected (scattered) light from each laser pulse is sequentially imaged by a CCD camera, and recorded digitally to a computer using a frame grabber. Software determines the displacement of a group of particles between a pair of capture images. To create one averaged velocity field for a particular scenario, approximately 50 pairs of instantaneous images of velocity fields are recorded for digital analysis.

The schematic of the integrated PIV system used in this study, seen in Fig. 4, is comprised of the following components: laser and light sheet optics, image capture system, synchronizer, particle generator and image analysis and display. The laser is a double pulsed 50 mJ Nd:YAG laser. Tracer particles whose motions are recorded using a Kodak Megaplus 10-bit CCD camera. Images are stored to a PC using an Epix PIXCI-D digital frame grabber. The frame grabber/camera combination has a double trig-

FIGURE 5

Velocity field with no miner: (a) first cut and (b) third cut.

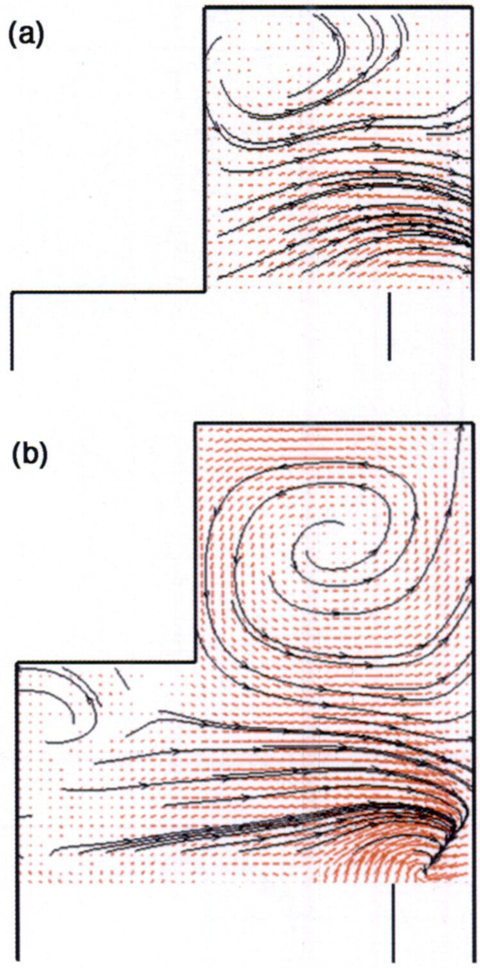


FIGURE 6

Halfway through the Number 3 cut.

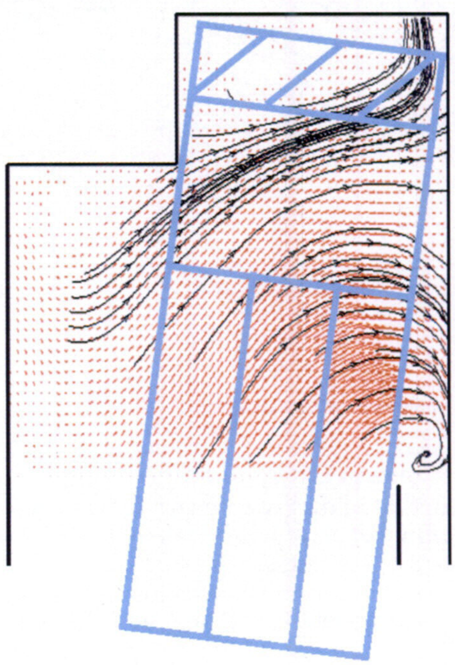


FIGURE 7

End of the Number 3 cut.

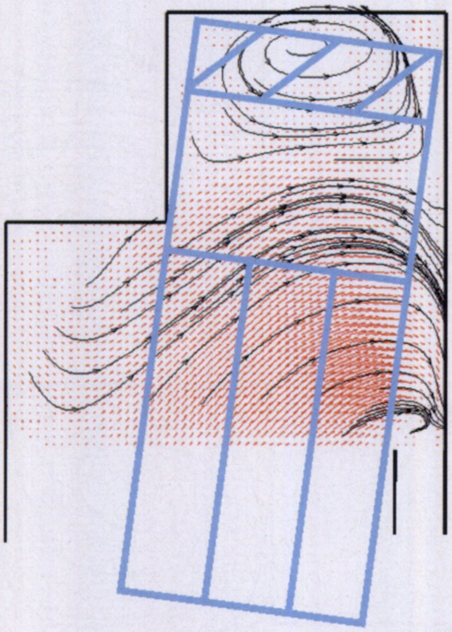


FIGURE 8

Start of the Number 4 cut.

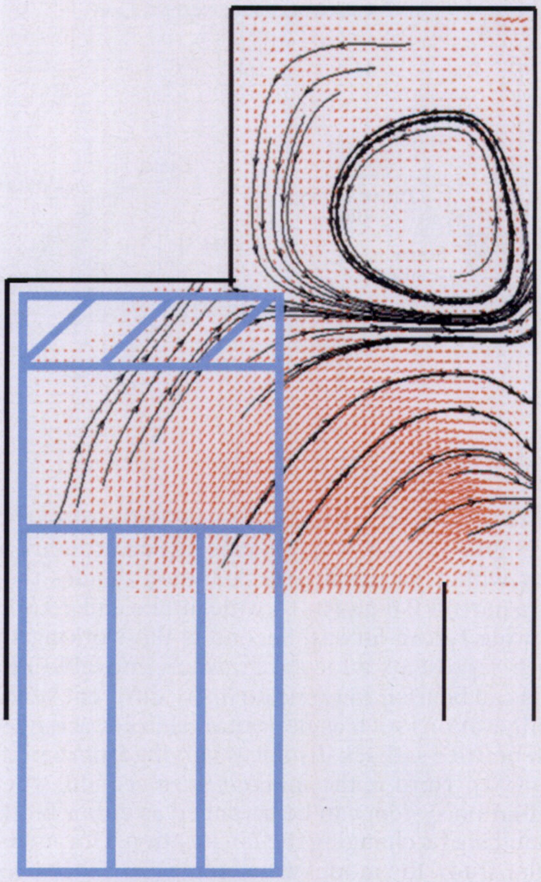
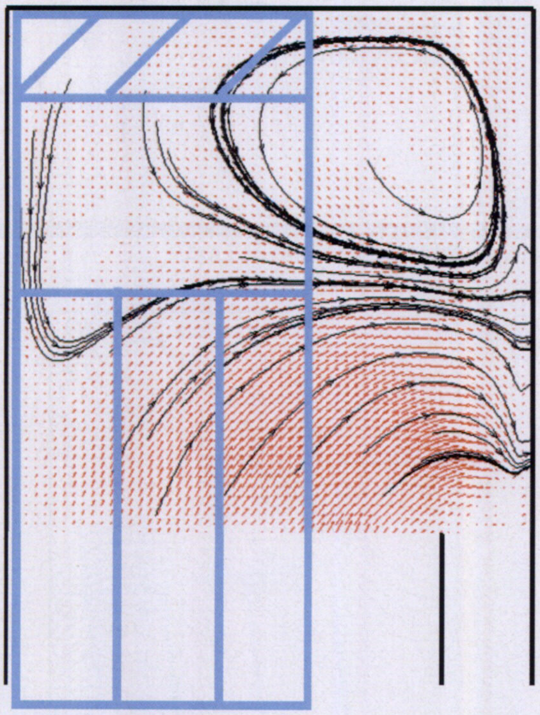


FIGURE 9

End of the Number 4 cut.



ger feature that allows two images to be acquired back-to-back within an extremely small time (~10 μs). Timing is controlled via a Taitech DG-100 timing control unit, which is monitored using an oscilloscope. This system is discussed in more detail in Turner et al. (2002).

Experimental data from scale modeling. By using the physical model of the face ventilation system (described above), a number of different mining scenarios representing coal mining processes using continuous miners with an exhaust face ventilation system for 6.1-m (20-ft) depth extended cuts were examined. For this particular study, as mentioned above, the four-cut sequence mining operation was adopted with the following three scenarios:

Scenario #1 — No equipment in the face area: To be able to show the general flow behavior (distribution) in the face area for the exhaust ventilation system, flow measurements were taken at the middle plane of the entry with no equipment. Figure 5 shows the velocity vectors in the face area just after the first cut (a) and the third cut (b) were completed. As can be seen from Fig. 5, most of the air is turning immediately back behind the curtain and only a limited amount is flowing toward the face. Nonetheless, whatever is getting into the face area creates a large circulation region.

Scenario #2 — Equipment in the face area: A scaled model of a continuous miner, simulating a Joy, Model 14 CM/10, was placed in the face area. Four locations for the continuous miner, depending on cutting sequence, were investigated. These locations were:

- halfway through the Number 3 cut,
- at the end of the Number 3 cut,
- at the beginning of the Number 4 cut and

FIGURE 10

Schematic of the miner model with extendable curtain.

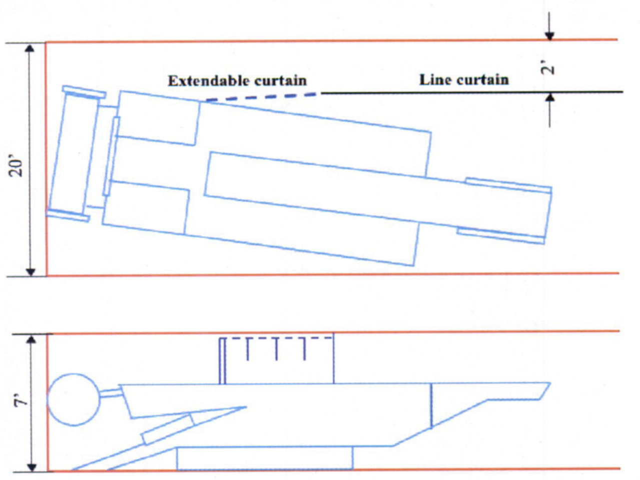


FIGURE 11

Start of the Number 3 cut with extendable curtain.

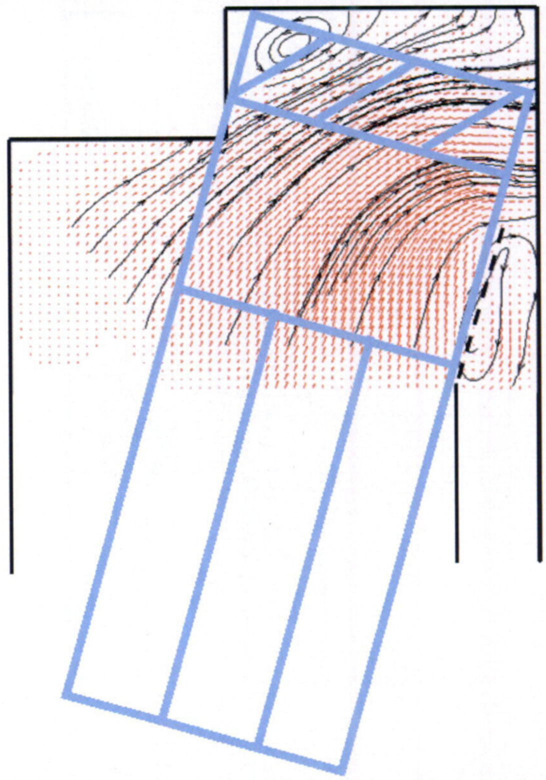
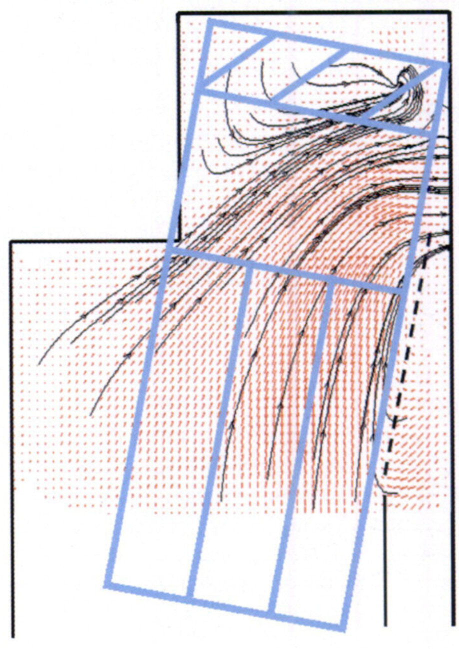


FIGURE 12

End of the Number 3 cut with extendable curtain.



- at the end of the Number 4 cut.

For all four arrangements, the line curtain setback was 6.1 m (20 ft) with a quantity of air equivalent to 2.1 m^3/s (4,300 cfm). Figures 6, 7, 8 and 9 show the velocity vectors measured at the plane above the continuous miner for the above arrangements, respectively. Figure 5 (b) corresponds to Fig. 7; note that the presence of the miner changes the flow field, but not significantly. Again, as can be see from all these figures, only a limited amount of air reaches the location where it is needed for gas dilution and dust removal. This means that at the face where the cutting head of the continuous miner is located there is a lack of fresh air. Therefore, in such a case there is a question of what can be done or what is being done to improve this situation. In the last 15 years, NIOSH, and previously the U.S. Bureau of Mines (Goodman et al., 1990; Colinet and Jankowski, 1994; Page et al., 1994), conducted extensive research to determine and develop the most effective ventilation schemes for extended cut mining methods. Several ventilation-enhancing devices, including continuous miners with machine-mounted scrubbers, extendable line curtains/flexible tubing, jet fans, spray-fans and combinations of these devices, were designed, tested and implemented (Divers and Volkwein, 1987; Goodman et al., 1990).

Scenario #3 — Equipment with ventilation-enhancing control device: To show improvements in the flow distribution in the face area for the above tested scenarios, the authors applied the well-known practice of an extendable curtain (Fig. 10) to the same geometry and conditions tested in Scenario #2. A simple extendable curtain forces more air toward the cutting head of the continuous miner. Figures 11, 12, 13 and 14 show the velocity vectors (flow distribution) for arrangements as described in Scenario #2 with the extendable curtain in place. Note that in all cases the ventilation is greatly improved at the active cutting face.

Conclusions

In accordance with the objective of this paper, using the existing scaled model of the face ventilation systems, the authors were able to demonstrate how useful this model can be for validation of the face ventilation plans and help in approval process.

Based on this study, the performance of the exhaust face ventilation system under Plan A (Fig. 3) for the four cut-sequence scenarios with a 6.1-m (20-ft) exhaust curtain setback is not very promising. Some mines have ob-

FIGURE 13

Start of Number 4 cut with extendable curtain.

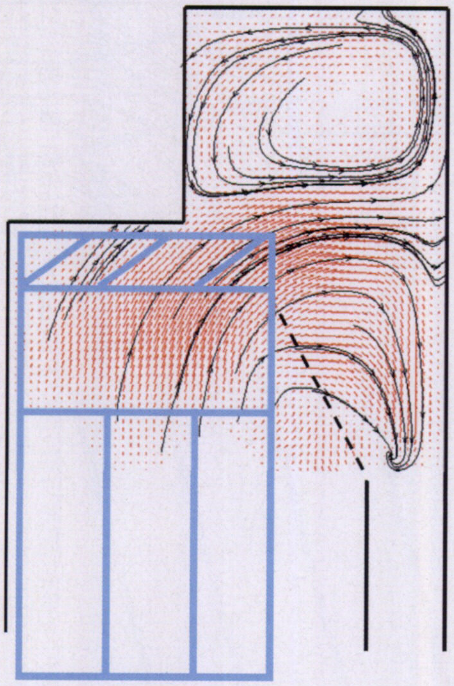
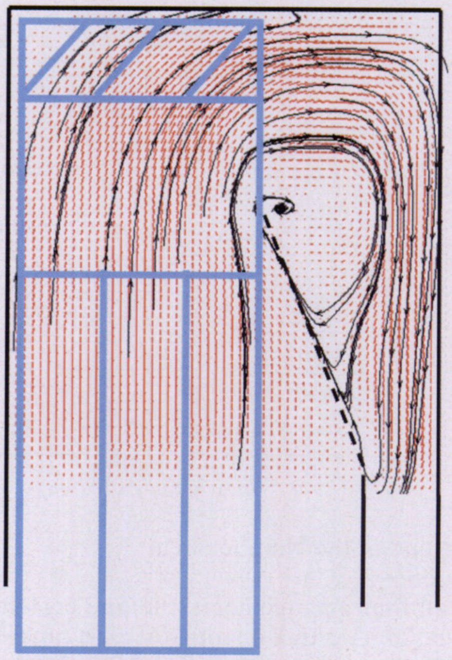


FIGURE 14

End of the Number 4 cut with extendable curtain.



tained MSHA approval for such scenarios, though none of these mines have significant methane gas to be controlled.

The last part of the study shows how using a relatively simple and inexpensive type of ventilation enhancement, i.e., applying a 3-m (10-ft) extendable curtain, the ventilation in the face area could be greatly improved. ■

Acknowledgment

This study was supported by the National Institute of Occupational Safety and Health under Grant No. R01/CCR415822. The authors express their gratitude to Joy Mining Machinery for providing the scale model of the continuous miner used during this study. The authors also thank Chuck Taylor of NIOSH for allowing us to use the full-scale mine facility in Pittsburgh for the full-scale PIV tests.

References

Colinet, J.F., and Jankowski, R.A., 1994, "Dust control considerations for deep-cut mining Wwhen utilizing exhaust ventilation and a scrubber," USBM Report of Investigations, RI 9615.

Divers, F., and Volkwein, J.C., 1987, "Guidelines for choosing face ventilation system," *Coal Mining*, October.

Goodman, G.V.R., Taylor, C.D., and Divers, E.D., 1990, "Ventilation schemes permit deep advance," *Coal*, October.

Hargreaves, D.M., and Lowndes, I.S., 2001, " Measurement and modeling air flow around a continuous miner in a development heading," *Proceedings,* Seventh International Mine Ventilation Congress, Krakow, Poland, June.

Moloney, K.W., and Lowndes, I.S., 1999, "Comparison of measured underground air velocities and air flows simulated by computational fluid dynamics," *Transactions of the Institution of Mining and Metallurgy*, 108 May-August.

Page, S.J., Mal, T., and Volkwein, J.C., 1994, "Unique water spray system improves exhaust face ventilation and reduces exposure to respirable dust on continuous miners in laboratory tests," *Journal of the Ventilation Society of South Africa*, October.

Turner, D., Wala, A.M., and Jacob, J.D., 2002, "Particle image velocimetry (PIV) used for mine face ventilation study," *Proceedings*, North American/Ninth U.S. Mine Ventilation Symposium," Kingston, Canada, June.

Wala, A.M., Stoltz, J.R., and Jacob, J.D., 2001, "Numerical and experimental study of a mine face ventilation system for CFD code validation," *Proceedings*, Seventh International Mine Ventilation Congress, Krakow, Poland, June.

Wala, A.M., Turner, D., and Jacob, J.D., 2002, "Experimental study of mine face ventilation system for validation of numerical models," *Proceedings*, North American/Ninth U.S. Mine Ventilation Symposium," Kingston, Canada, June.