Developments in Longwall Ventilation

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ABSTRACT
Rapid development in longwall mining technology has brought significant changes in panel layout and geometry. These changes require adaptations in the ventilation system to provide sufficient air quantities in longwall face and bleeder areas. At CONSOL, various longwall bleeder systems in the Pittsburgh No. 8 Seam have been studied with detailed ventilation surveys. Computer model network simulations were conducted from these surveys to study the effects of different bleeder configurations and ventilation adjustments. This paper examines the relationships between the longwall face air quantity and the convergence in the tailgate-to-bleeder entries, number of development entries, bleeder fan pressure and the tailgate ventilation scheme. It shows that, using conventional ventilation patterns, the face air quantity may be limited if the gob caves tightly. In such cases, modification of the ventilation pattern to an internal bleeder system, combined with appropriate tailgate ventilation and higher bleeder fan pressure may be required. Experience in CONSOL's operations has proven this method successful especially in mines that changed from four-entry to three-entry longwall development.

KEYWORDS

Mine Ventilation, Longwall, Underground Mining, Coal, Pittsburgh Seam, Bleeder System, Network Modeling, Internal Bleeder, Three-Entry Development, Longwall Face Air Quantity, Fan Pressure, Longwall Gob, and High-Pressure Bleeder Fans.

INTRODUCTION

CONSOL Inc. began operations in 1864 and, since 1998, has been a majority-owned subsidiary of Rheinbraun AG, Germany. The company is the third-largest coal producer overall and largest producer of coal from underground mines in the United States.

In 1997, CONSOL mines produced 64.7 million t (71.3 million st) from 24 mining complexes. 94.1 % of this production came from underground mines, the remainder from surface operations.

CONSOL is also the largest coal exporter in the U. S. In 1997, exports totaled 10.6 million t (11.7 million st).

Mining operations are located in West Virginia, Pennsylvania, Virginia, Illinois, Kentucky, Ohio, and in Alberta, Canada. In 1997, total employment was 7,111, and total reserves were 4.3 billion t (4.76 billion st).

CONSOL operates 19 longwall-mining systems and is the leading longwall coal producer in the country. The Enlow Fork and Bailey mines are the No. 1 and No. 2 underground producing mines in the U. S. with a combined production of 14.4 million t (15.9 million st) in 1997.

Over the past 20 years, longwall mining in the United States has experienced large increases in production and productivity. CONSOL's average longwall productivity increased from just over 1,000 clean tons per machine shift in 1981 to over 4300 in 1997 with some longwalls averaging over 6,000 clean tons per machine shift. Table 1 shows some characteristic data for each of these stages.

Table 1. Changes in longwall geometry and panel development.

Time Period	Face Width	Panel Length	Gate Entries
1970-1980	150 m (500 ft)	1,200 m (4,000 ft)	4
1980-1990	225 m (750 ft)	1,800 m (6,000 ft)	4
1990-present	330 m (1,000 ft)	2,700 m (9,000 ft)	3

Over time, longwall panels have undergone significant changes:

- Increasing panel lengths and widths reduce the number of longwall moves and the exposure to move-related hazards.

- Reducing the number of development entries from four to three and increasing mining block sizes have improved roof stability.

Longwall ventilation systems must be adapted to accommodate these changes in order to provide sufficient air quantities in the working places as well as in the bleeder systems.

Better ventilation survey techniques and advanced computerized network modeling have helped us study these requirements and changes in the ventilation system and enabled us to re-define the ventilation requirements for longwall systems. The following sections highlight some of these changes and their effect on longwall ventilation.

LONGWALL VENTILATION PATTERNS

In the Pittsburgh No. 8 Seam in the Eastern United States, longwall panels are typically developed with four or three gate entries and three to four bleeder entries at the back end of the panel, as shown in Figure 1.

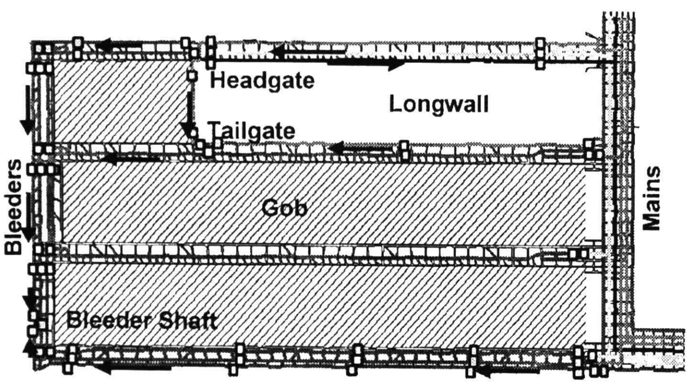

Figure 1. Layout for conventional longwall bleeder ventilation.

Longwall panels are mined on retreat, and the development entries are utilized as a bleeder system surrounding the gob area.

A common airflow pattern is indicated by the arrows in Figure 1. In four-entry development, the entries on the headgate side outby the face are: Belt, track, intake (escapeway) and a separate intake entry. In three-entry systems (as shown in Figure 1), track and intake are combined to one entry. The separate intake entry becomes the primary escapeway.

Inby the longwall face the headgate entries become part of the bleeder system. These entries are separated from the intake side by check curtains inby the headgate. On most longwalls, the gob pressure inby the face causes the roof to fall in the belt entry. These falls can extend through the crosscuts into the adjacent entry.

The stopping line to the separate intake entry is maintained intact, and this entry is kept open for access to the bleeder entries. Fresh air from this entry is often used to ventilate the face, especially if there are restrictions on track air velocity. This requires tearing down and later rebuilding the stoppings at the headgate, usually in combination with the installation of doors for supply haulage.

Belt air may be routed toward the face or away from it. Routing belt air toward the face produces additional intake quantity due to reduced leakage in the headgate.

At the back of the longwall panel, three, four or five bleeder entries are mined. These entries are generally referred to as the "bleeders." The first of these entries serves as the longwall setup entry and caves after the panel starts. Caving can extend through the crosscuts and into the adjacent entry.

Generally, two bleeder entries are open to maintain sufficient bleeder air quantities. Some operations separate the two outside bleeder entries by a barrier pillar to improve roof stability.

The bleeder system is ventilated by a separate shaft and exhaust fan in the bleeders of the first panel. This bleeder fan controls longwall ventilation since most or all longwall return air is exhausted through the bleeder system.

On the longwall tailgate side, the entries inby the face become common bleeder entries as the stopping lines between the entries crush out. Between mined-out gobs, these entries generally converge since they are subject to high overburden stresses. In fact, from a geotechnical viewpoint, this caving is desirable as it reduces horizontal stresses in the tailgate area.

Outby the face, the stopping line between the tailgate and the adjacent bleeder entry is maintained intact. At the start of each longwall panel, the tailgate is usually ventilated with intake air. The air mixes with the return air from the face and is then routed to the bleeder fan through the remaining open area between the gobs. As the longwall face advances away from the bleeders, it becomes increasingly difficult to route sufficient air to the bleeder shaft. Therefore, it may eventually become necessary to put the tailgate on return.

The condition most difficult to ventilate (i.e., the worst case in a ventilation projection) occurs just before the longwall panel is mined out. At this point it is relatively easy to provide fresh air to the face at the intake (headgate) side, but the long path through the tailgate to the bleeders will restrict return air flow.

BLEEDER SYSTEM SURVEYS

To better understand the function of the bleeder system in a longwall mine, CONSOL has conducted several special bleeder system surveys. Figure 1 shows a typical arrangement for such a survey.

From these surveys, the following parameters are determined.

- Resistances in the development and bleeder entries

- Airflow across gob areas
- Remaining equivalent orifice in the middle entry or entries inby the active tailgate and between two gobs
- Leakages between development entries

Since many of the bleeder entries cannot be traveled, airflow patterns in these entries and across the gobs must be determined indirectly from quantity and pressure readings along the outside entries of the bleeder system. Figure 1 shows survey locations as yellow squares. These stations are arranged to capture airflows and pressures in all accessible areas of the bleeder system. Readings of intake to the bleeder system are taken at the headgate and tailgate of the longwall, and at each inlet to the bleeders from the mains. If possible, additional readings are taken along the tailgate outby the longwall face.

Especially important are sets of readings in the tailgate of the first panel. Stations along these entries are spaced every 300 to 600 m (1,000 to 2,000 ft). Increasing quantities in these stations indicate the amount of airflow across the first gob.

The bleeder survey is completed with sets of readings across the bleeders inby and outby each set of development gates and at the bleeder fan. From the readings in the bleeders, the amount of airflow through each individual set of development entries is captured.

The overall quantity balance, together with the measured pressures, determines the airflow pattern in the bleeder entries and across the gob. In the Pittsburgh Seam mines, there is a wide range of gob permeabilities. Typical air quantities across gobs range from zero up to 12 m^3/s (25,000 cfm).

Assessment of the remaining equivalent orifice on the tailgate inby the face is the most important task in a bleeder survey since this orifice has a significant impact upon the air quantity available to ventilate the longwall face. Airflow in this "tailgate-to-bleeder" entry can only be determined indirectly because no portion of the entries is accessible.

The bleeder survey data provide a network model to assess longwall ventilation and to study the effects of longwall face advance on air quantities at the face and in the bleeder system. These bleeder models were also used to simulate the effects of changes in bleeder design and ventilation patterns. Results of these network simulations are presented in the following sections.

THREE-ENTRY VS. FOUR-ENTRY DEVELOPMENT

Figure 2 shows results of bleeder ventilation simulations comparing three-entry to four-entry development for a number of Pittsburgh Seam mines. The graphs show the longwall headgate quantity (typically recorded at No. 10 shield) as a function of the equivalent orifice in the tailgate-to-bleeder branch. These orifices, as determined from bleeder system surveys, range from about 0.7 m^2 (7 ft^2) for a tightly-caving gob up to 4.6 m^2 (50 ft^2). for a gob that remains fairly open. For most Pittsburgh Seam mines, the equivalent orifice ranges between 2 and 3 m^2 (20 to 30 ft^2).

All cases were run in a sample bleeder model representing the typical features of a longwall ventilation system in the Pittsburgh Seam. The configurations studied represent the worst cases for longwall ventilation, i.e., cases where the longwall face is close to the end of the panel. The tailgate was kept on 2.4 m^3/s (5,000 cfm) intake air, and the bleeder fan pressure was kept constant at 50 hPa (20 in. WG). The models are not specific to any mine since it was necessary to keep all entry parameters, panel dimensions, etc. constant. Therefore the numbers must NOT be regarded as absolute quantities but rather represent trends.

The curves in Figure 2 show that the headgate quantity depends to a large extent on the equivalent orifice area. It shows that Mine "H" with an opening of close to 4.6 m^2 (50 ft^2) can easily achieve 19 m^3/s (40,000 cfm) in a three-entry development. In mines where the orifice area is 2.3 m^2 (25 ft^2), four entries are necessary to achieve 16 m^3/s (35,000 cfm), while three-entry development yields less than 9.4 m^3/s (20,000 cfm). Ventilation of three-entry systems under these conditions requires a modified ventilation scheme.

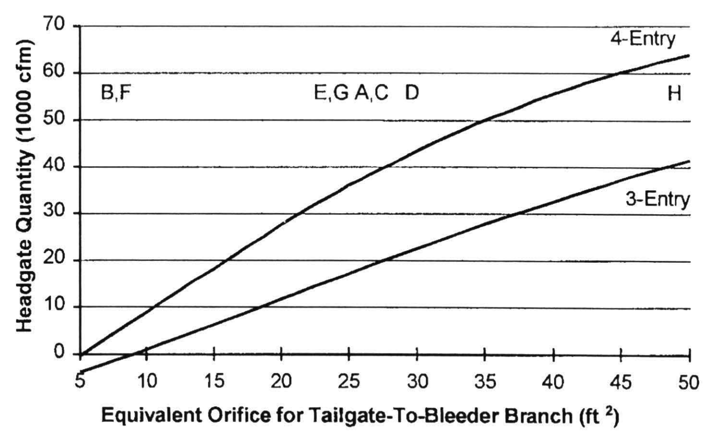

Figure 2. Comparison of three-entry and four-entry development.

These modifications, which have been successfully applied to achieve sufficient headgate air quantities at several Pittsburgh Seam mines, are described in the following sections.

TAILGATE ON RETURN VS. INTAKE AIR

One possible improvement for mines with tighter tailgate-to-bleeder branches is to split the air at the longwall tailgate and to route part of it toward the mains.

Results of the bleeder model simulations are shown in Figure 3.

Again, the graphs show trends rather than absolute numbers since all model parameters have been kept constant and do not represent data for any particular mine. Figure 3 shows that the longwall headgate quantity is almost directly proportional to the quantity carried in the tailgate entry outby the face. Three curves were selected for tailgate-to-bleeder, equivalent orifices of 0.7, 2.0, and 4.6 m^2 (7, 22 and 50 ft^2). Negative quantities on the abscissa indicate tailgate on intake air while positive quantities indicate tailgate on return air. Cases represent three-entry development with the bleeder fan running at 50 hPa (20 in. WG).

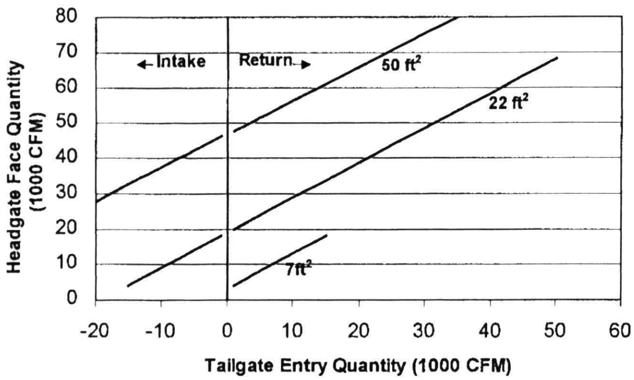

Figure 3. Longwall face quantity as a function of tailgate quantity.

In mines where the equivalent orifice is 5 m^2 (50 ft^2), adequate ventilation can be achieved with up to 4.7 m^3/s (10,000 cfm) of intake air on the tailgate. Equivalent orifices of 2.2 m^2 (22 ft^2) require a minimum of 7 to 9.5 m^3/s (15,000 to 20,000 cfm) return air in the tailgate.

In mines with tightly-caving gob entries, the achievable headgate quantities are not sufficient. Note that the curve for 0.7 m^2 (7 ft^2) ends at about 7 m^3/s (15,000 cfm) return air in the tailgate. Beyond this point, it would still be possible to increase the headgate quantity, but in a conventional bleeder arrangement, a positive split toward the bleeders cannot be maintained at the tailgate. In other words, if too much air is pulled to the return from the tailgate outby, there is a potential for drawing air out of the gob, resulting in inadequate air quality at the tailgate.

This practice is known as "putting the tailgate on return air."

HIGH-PRESSURE BLEEDER FANS

The graph in Figure 4 illustrates the effect of increasing the bleeder fan pressure. The model parameters used were for an equivalent orifice of 2.0 m^2 (22 ft^2), three-entry development, and 2.4 m^3/s (5,000 cfm) of return air ventilating the tailgate.

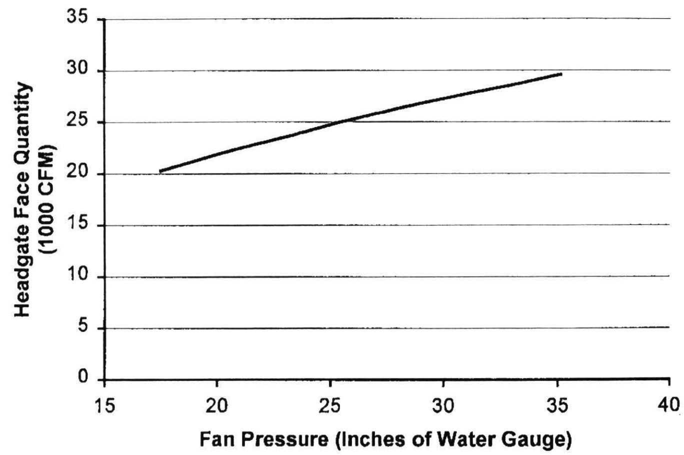

Figure 4. Effect of fan pressure on headgate quantity.

The curve shows that doubling the operating pressure of the bleeder fan from 45 to 89 hPa (18 to 36 in. WG) only results in less than 50 % increase of the headgate quantity. This demonstrates that, in conventional bleeder systems, longwall ventilation depends almost entirely on the equivalent orifice of the tailgate-to-bleeder branch. The relatively flat slope of the curve indicates that, in most cases, increasing the bleeder fan pressure or "putting a bigger fan on the bleeder shaft" does not lead to a significant improvement in longwall ventilation quantity. Higher pressure on the bleeder system alone may therefore not be sufficient to achieve the desired face quantities on the longwall. In combination with other measures for improved ventilation, however, a higher-pressure bleeder becomes an important component of the ventilation system.

INTERNAL BLEEDER SYSTEMS

Putting the tailgate on return air and increasing the bleeder fan pressure both have limitations in conventional bleeder systems if the tailgate-to-bleeder entry is severely restricted by convergence. In order to provide sufficient air to the longwall face, it may become necessary to provide an alternate route for the return air from the longwall face. This can be done by modifying the conventional bleeder system with the addition of an "internal bleeder."

As shown in Figure 5, the return air from the longwall is split at the tailgate, directing part of the air through the remaining center entry on the outby tailgate and routing the remainder directly to the bleeders. The tailgate may be ventilated on intake or return air. The stopping line between the tailgate and the center entry is maintained up to the face. This arrangement forces the tailgate split point inby the face, thus avoiding pulling gob air into the working face. The outby split on the center (former track) entry is then routed to the bleeder fan via a system of "ladder" entries adjacent to the longwall recovery chutes of the previous panels.

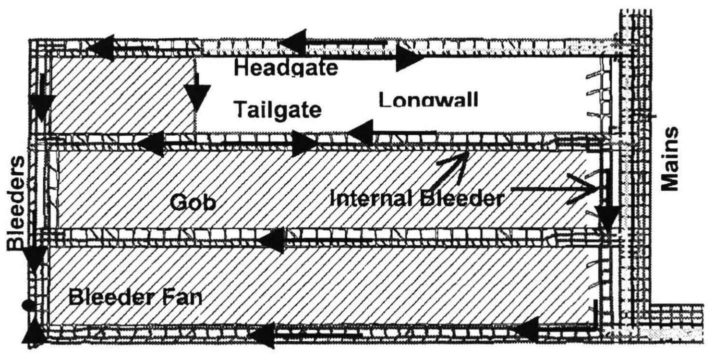

Figure 5. Internal bleeder arrangement for longwall ventilation.

Advantages of this internal bleeder arrangement are:

- The entire gob is surrounded by a system of bleeder entries.
- The higher pressure of the bleeder fan can be utilized for both tailgate splits.
- Putting the tailgate on return air does not pull gob air out from behind the shields into the working areas since a stronger pull can be maintained on the internal bleeder.

The internal bleeder system responds to increased fan pressures better than the conventional bleeder system.

Figure 6 shows the effect of such an internal bleeder arrangement. The headgate quantity is shown as a function of bleeder fan pressure. All data are for a three-entry longwall system with the 5,000 cfm return air on the tailgate.

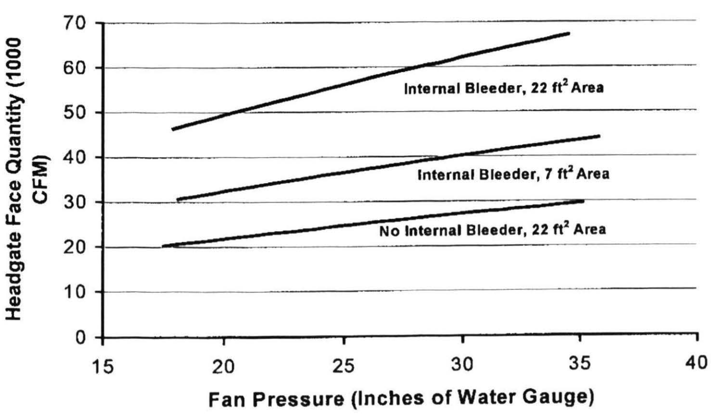

Figure 6. Internal bleeder system vs. conventional bleeder system.

The bottom curve represents a conventional bleeder arrangement with the longwall face close to the end of the panel (worst case). The equivalent orifice for the tailgate-to-bleeder branch is 2 m^2 (22 ft^2).

The curves for the internal bleeder system show that this arrangement, combined with an increased fan pressure, can provide adequate longwall ventilation even in cases where the tailgate-to-bleeder entry has only small equivalent orifice areas. Note that the worst ventilation case for the internal bleeder arrangement occurs when the longwall face is approximately at mid-panel. At the start of the panel, ventilation through the inby tailgate is sufficient, and near the end of the panel, most of the face air is routed through the internal bleeder system.

SUMMARY AND CONCLUSIONS

Over the past 20 years, longwall mining has experienced significant changes in panel layout and geometry. These changes demand better-adapted and capable ventilation systems.

From bleeder system ventilation surveys, modeling data have been gathered to study the effects of various modifications to the ventilation arrangements around a longwall panel. Advanced computer modeling has enabled us to study in detail the effects of:

- Remaining equivalent orifice in the middle entry between two gobs, especially in three -entry development
- Resistances in the bleeder system entries
- Airflow across gob areas

Projections from these network computer models show the relationships between the longwall headgate quantity and remaining equivalent orifice in the tailgate-to-bleeder branch, the quantity and direction of airflow in the tailgate entries outby the face, and the bleeder fan pressure.

Simulations also show the effects of a modified internal bleeder arrangement in combination with the above parameters.

For selected mines in the Pittsburgh Seam, equivalent orifices for the tailgate-to-bleeder branch on the active longwall range between 0.7 and 4.6 m^2 (7 and 50 ft^2). While it is relatively easy to ventilate longwalls with large remaining orifices in a conventional pattern, mines with tightly caving gobs require modified ventilation patterns. Solutions include putting the tailgate on return air, increasing the bleeder fan pressure, and creating an internal bleeder system. All three methods and combinations thereof have been successfully applied at CONSOL mines.