INVESTIGATION INTO THE PRACTICAL USE OF BELT AIR AT US LONGWALL OPERATIONS

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ABSTRACT

The use of belt air as an intake source at longwall operations has greatly changed over the past decades. The practical considerations for the use of belt air are controlled by a variety of factors including airflow quantity and velocity, coal methane content, methane desorption rates, coal mining rate, belt length, stopping leakage, and the number of gateroad entries.

At longwall operations, the advantages and disadvantages of belt air are different for gateroad development and longwall panel extraction. During gateroad development, the use of belt air to ventilate the working section will reduce the leakage from the intake to the belt compared to the belt air being ventilated outby the working sections because of lower pressure differentials. A greater quantity of airflow will reach the last open crosscut with belt on intake than outby, given the same amount of pressure and airflow available at the mouth of the section.

This paper will investigate the current ventilation practices regarding the use of belt air during gateroad development and longwall panel extraction. Operating considerations regarding air quantities and pressures to deliver the required airflow will be investigated using ventilation network modeling.

INTRODUCTION

In December, 2007, the Technical Study Panel on the Utilization of Belt Air released a report concerning the use of belt air in US coal mines (Mutmansky JM, et al., 2007). The panel's report covered a wide range of topics and their recommendations should be considered in all longwall ventilation systems. The ventilation system for each longwall primarily depends on the number of entries used in the gateroad development. As of February, 2008, there are approximately 48 operating longwall panels in the United States mining coal (Fiscor, 2008):

- 5 – Four-entry (Blue Creek - Mary Lee seams in Alabama / Pocahontas #3 seam in Virginia / Powelton seam in West Virginia) panels
- 39 – Three-entry panels
- 4 – Two-entry (Utah) panels

The four-entry gateroad longwalls are characteristically located in the gassiest coal seams in the United States. To handle high methane emissions during development, the outer two entries are placed on return air with the middle two entries on intake air.

The most common three-entry system generally consists of a belt entry (ventilating the working section or not), a middle intake, and a dedicated return (Figure 1). Belt air can either be directed to the working section or not. For the rest of this paper airflow in the belt that is sent to the working section will be called 'belt air' and airflow in the belt that is not used to supply the working section but moving away, will be called 'belt outby'. The middle travelway entry may or may not have an installed track but is the primary escapeway unless trolley haulage is being used.

All two-entry gateroads are located in Utah where ground control issues preclude the use of developments with more than two entries. The yielding pillars that are required to control possible bump conditions cannot easily and safely be developed with a three-entry system. During development, the belt is located in the return and the travelway is in the intake. During panel extraction both entries are used to supply intake air to the end of the longwall section. It is important to remember that there are several safety considerations that must be instituted as conditions for granting a petition for modification to allow the belt entry to be used as a section return on development and as an intake split on retreat.

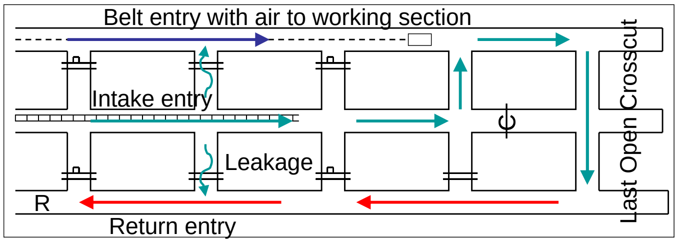

Figure 1. Model layout (belt air used to ventilate working section).

The airflow requirements for gateroads are controlled by a number of factors, primarily methane emissions at the face and along the solid ribs. Emissions from the active face are assumed to be independent of the length of the gateroad and require sufficient fresh airflow at the last open crosscut for dilution. If the intake air contains methane, a greater airflow is required.

For shorter gateroads, development methane liberation in the face area is the primary factor influencing airflow requirements. As gateroad distance increases, however, the exposed rib length increases and a greater amount of methane flows into the ventilation system mainly from the outer coal ribs. This methane inflow rate is a function of the coal's methane content and desorption rate. However, for long gateroads, rib emissions can far exceed the methane liberated at the development face. In this case, the total amount of air available at the section mouth for dilution of the rib emissions limits gateroad development distance. All of these methane emission sources can be affected by pre-mining or in situ methane drainage.

Model set up

VnetPC 2007 (Mine Ventilation Services, Fresno, CA) ventilation simulation software was used to analyze gateroads of various lengths using 300-meter long segments (984-ft) each with 6 crosscuts. Total pressure across the mouth of the section was held constant at 1 kPa (4.1 inches water gauge). Entry sizes of 4.7 m x 2.4 m (15.5 ft x 8 ft) or 6.1 m x 1.82 m (20 ft x 6 ft) both yield a similar resistance of 0.025 Ns^2/m^8 (22.4 $x10^{-10}$ $in{\cdot}min^2/ft^6$) per 300-m (984-ft) segment using common k-factors (Hartman et al., 1997). The belt entry because of the high equipment blockages was given a resistance 20% higher 0.030 Ns^2/m^8 (27.9 $x10^{-10}$ $in{\cdot}min^2/ft^6$) than the other entries. Stopping resistances were set at 2000, 2500, 3500, 5000, 7500 and 10,000 Ns^2/m^8 (179, 223, 313, 448, 671 and 895 $x10^{-10}$ $in{\cdot}min^2/ft^6$) to represent poor to excellent stopping construction (Oswald, 2008). Total lengths of gateroads modeled ranged from 300 m (984 ft) to 6300 m (20,670 ft). Crosscuts were set on 50-m (164-ft) centers with 6 stoppings grouped together to indicate standard gateroad crosscut layouts. Longer 60-m (197-ft) centers were also modeled to indicate the longwall operation with crosscuts farther apart, but the results did not differ that much from the basic case if a higher stopping resistance was used. For example, six-5000 Ns^2/m^8 (448 $x10^{-10}$ in·min^2/ft^6) stoppings are almost identical to five-3500 Ns^2/m^8 (313 $x10^{-10}$ in·min^2/ft^6) stoppings if placed in parallel over the same 300-m (984-ft) segment (Table 1) where equivalent parallel resistance is equal to stopping resistance / (number of stoppings)^2.

Table 1. Equivalent parallel resistances.

Resistance	Parallel Stoppings		
Ns^2/m^8	6	5	4
	(50 m apart)	(60 m apart)	(75 m apart)
10000	278	400	625
7500	208	300	469
5000	139	200	313
3500	97	140	219
2500	69	100	156
2000	56	80	125

AIRFLOW AT THE LAST OPEN CROSSCUT

The amount of airflow reaching the last open crosscut is controlled by several factors:

1. Number of entries and their layout.
2. Stopping resistance.
3. Number of stoppings.
4. Entry resistance.
5. Pressure differential across the entries.
6. Limitations in entry velocities or pressures across stoppings.

With the same pressure differential at the section mouth, a three-entry system can deliver more air to the last open crosscut using 'belt air' towards the working sections rather than 'belt outby' the face (Figure). Using 'belt air' to ventilate the working sections reduces the quantity of leakage from the middle intake into the belt, but increases the possibility that the belt entry may eventually carry more airflow than the intake or be at a higher pressure relative to the intake. This establishes a limit to the maximum gateroad length that can be developed with the belt on intake air. Figure illustrates that a maximum development distance of 3300 m (10,800 ft) is obtained when placing the belt entry on intake air and using a stopping resistance of 2000 Ns^2/m^8 (179 $x10^{-10}$ in·min^2/ft^6). For gateroad lengths exceeding 3300 m (10,800 ft), total pressure or airflow in the belt entry exceeds those values in the intake entry. For all six curves, the resistances of the entries are shown in the previous section and the pressure at the mouth of the section is 1 kPa (4.1 in w.g.). The relative pressure of the belt to the intake was 75% for the 'belt air' curves and 20% for the 'belt outby' curves. As the stopping resistances increase or if the belt entry is placed on 'outby' airflow, maximum development distances can increase. The ideal cases of no leakage through the stoppings are also shown in Figure 2.

In addition to stopping resistance, maximum gateroad development length is impacted by the pressure differential between intake and belt entries at the section mouth. Figure 3 shows the maximum gateroad development distance that keeps intake entry airflow higher than belt entry airflow. The percentages in the graph are the total pressures in the belt entry relative to those in the intake airway measured at the section mouth. "LOC" (last open crosscut) and "Mouth" refer to the locations that limit gateroad development.

Total pressure in the belt airway cannot be lowered too much; in that a lower relative pressure translates to a lower belt airflow measured at the section mouth. With total pressure in the belt entry at 70% of the total pressure in the intake entry, gateroad development is not restricted by the high belt airflow at the last open crosscut but, rather, by low belt airflow at the section mouth. Using the guidance of the Technical Study Panel on the Utilization of Belt Air of a minimum air velocity of 100 ft/min (0.5 m/s) and an entry opening of 11.2 m^2 (120 ft^2), the minimum airflow quantity is calculated to be 5.6 m^3/s (12,000 cfm) at the section mouth for these models. Using the above example of the belt entry pressure at 70% of the intake entry pressure and stopping resistances of 7500 Ns^2/m^8 (671 $x10^{-10}$ in·min^2/ft^6), the maximum gateroad development is not limited to 6000 m (19,700 ft) by airflow at the LOC, but by the low airflow at the mouth of the section when the gateroad is developed to 4800 m (15,700 ft).

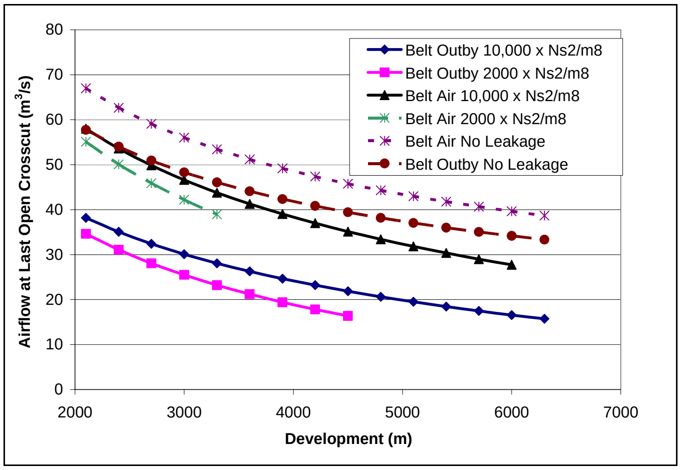

Figure 2. Airflow at last open crosscut with belt on intake and return with different stopping resistances (Ns^2/m^8)

The maximum distance for gateroad development occurs when both the restriction on airflow at the last open crosscut and minimum airflow entering the belt at the mouth of the section occur at the same time. The 75% LOC line represents the maximum development distance while balancing both requirements at the LOC and mouth of the section. In the above example of 7500 Ns^2/m^8 (671 $x10^{-10}$ in·min^2/ft^6) stoppings, if the total pressure in the belt is 75% of the intake at the mouth of the section, the maximum development was calculated to be 5100 m (16,700 ft), not 4800 m (15,700 ft).

The purpose of the gateroad development is the mining of the subsequent longwall panel. Ventilation of the gateroad development should not be the only consideration for using 3 or 4 entries. Ultimately, the gateroads provide important ventilation flow paths through the worked-out area and have significant impact on the bleeder system performance. While this paper covers belt air issues on gateroad development, the important future use of the gateroad and the bleeder system should be considered.

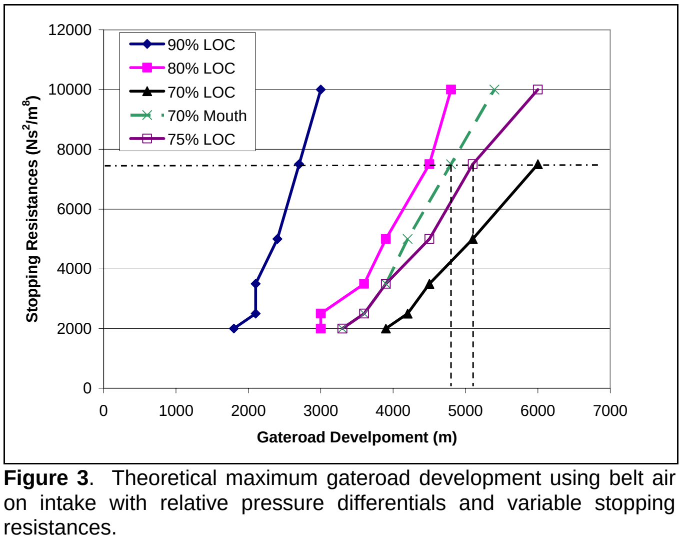

Figure 3. Theoretical maximum gateroad development using belt air on intake with relative pressure differentials and variable stopping resistances.

LIMITATIONS OF BELT AIR

Using belt air to ventilate the working sections does make it possible for a higher percentage of intake air to reach the last open crosscut because leakage is reduced. However, a new problem arises with the belt entry carrying more air than the intake entry.

Using the same model parameter as before, the maximum gateroad length that can be ventilated using belt air is controlled by two factors: 1) leakage into the belt and 2) methane emissions. Excessive leakage into the belt near the start of the section and continued leakage from the intake into the return can cause the belt to be at a higher relative pressure than the intake at the end of the gateroad. Eventually the belt will be supplying a greater airflow than the intake to the working section, contrary to regulations (CFR 75.350(b)(6)) [Code of Federal Regulations, 2008]. When belt air starts leaking into the primary intake, the major concern is that a belt fire will contaminate the intake air split with CO and smoke and make escape more difficult. The belt entry will have a higher resistance than the intake entry due to obstructions such as belt structure, belt take-ups, etc. Air from the belt entries will leak into the intake entries long before the belt is carrying more air than the intake as shown in Figure 4. Figure 5 shows that once leakage into the return from the intake approaches 41%, the ventilation system, regardless of stopping resistance, has a problem with the belt entry being at a higher pressure than the intake.

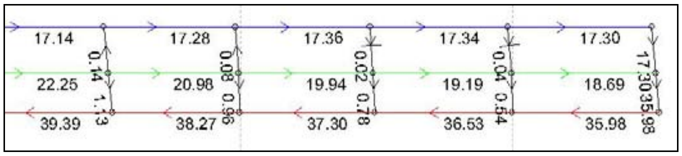

Figure 4. 4200-m model with 1 kPa of pressure at the mouth of the section and 5000 Ns^2/m^8 stoppings showing leakage from belt into intake entry (0.02 and 0.04 m^3/s) before belt entry transporting more airflow than intake.

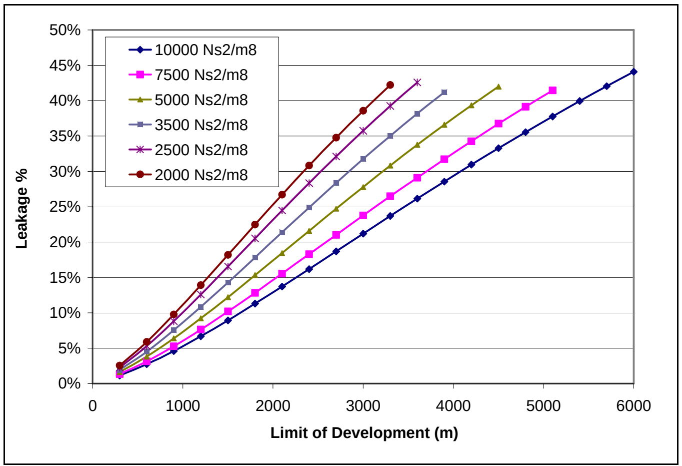

Figure 5. Gateroad development limit using belt air at 75% of pressure of intake entry with different stopping resistance, leakage total is from intake into return.

The use of point-feeding the belt entry is a common practice and a beneficial one for shorter gateroad developments. This paper is concerned with calculating the maximum distance that a gateroad can be developed if ventilation is the limiting factor. The use of point-feeding will decrease the maximum distance that can be ventilated before the belt is at a higher pressure then the intake. For this reason, point-feeding is not modeled in this paper.

Increased Belt Resistance

The belt resistance was set at 20% higher than the other two entries but the belt resistance was also modeled at 0% and 40% greater than the other two entries to represent the increased obstruction of the belt assemblage. There was no significant change to the pattern of airflow in the belt or in the leakage quantity from belt to intake. The two controlling factors for the development of very long gateroads are stopping resistance and pressure differential at the mouth of the section.

The Mixing Problem

The ventilation models show that a higher percentage of airflow will reach the working section if the belt is placed on intake rather than return assuming similar resistances. The methane loading of the intake air will be quite different and will affect the ability to ventilate the active workings. The main assumption is that little methane will enter into the middle intake while methane will bleed into the outer entries off of the solid coal rib. When the outer belt entry is used to ventilate the working section, methane emissions from the rib will be carried to the active face and can increase the starting methane concentrations at the working section. Higher starting methane levels for the combined intake and belt air would require a higher airflow quantity to dilute the methane liberated in the working places. The final methane emissions at the last open crosscut can be calculated by the following formula:

$$C_F = \frac{(C_I \times Q_I) + (C_B \times Q_B)}{Q_I + Q_B}$$

Where:

C_I = Intake concentration
Q_I = Intake air quantity
C_B = Belt concentration
Q_B = Belt air quantity
C_F = Concentration where the belt air and intake air mix

The quantity of methane released by the coal transported on the belt changes during panel development and panel extraction. The quantity of coal mined by the continuous miner is less than 10% of what a shearer produces and is more cyclical during the shift. Methane emission rate of the mined coal on the belt during panel development is low when compared to the rib emissions rate. For example, 26 m^3/s (55,000 cfm) supplied by the intake track entry, compared to 14 m^3/s (30,000 cfm) of intake air and 12 m^3/s (25,000 cfm) of belt air, may not have the same diluting ability. Assuming the intake track entry has a methane concentration of 0.1%, and the belt 0.3%, the final mixed methane concentration will be 0.19% using the above equation. This represents a reduction of 10% of the fresh air to dilute the working places of methane on a per m^3 (ft^3) basis but this example does not have a higher airflow quantity usually associated with using belt air to ventilate the working sections. In gassy 4-entry longwall operations, adverse rib emissions preclude the practice of bring outer entry airflow towards the working section.

Panel Extraction

During longwall panel extraction, the belt can be fully loaded with coal that can add a significant amount of methane to the air used to ventilate the longwall headgate. With so much methane being liberated by the coal, it may be more appropriate to ventilate the belt airflow outby the longwall section and convert the gateroad development return entry into a secondary intake. This has a number of benefits, such as increasing safety with two semi-isolated escapeways and supplying a greater quantity of airflow to the headgate end of the longwall face at a higher pressure.

For example, a longwall panel with a length of 4270 m (14,000 ft) was initially ventilated with belt air and one intake entry. Upon longwall panel startup, airflow was reduced to the return entry to maintain adequate airflow across the longwall face. Soon thereafter, a problem arose with high methane concentrations in the belt entry once the shearer had been operating for one cut cycle to load the belt with coal. A methane concentration of 0.7% on 12 m^3/s (25,000 cfm) airflow at the working section of the belt entry necessitated a major change to the ventilation system (Figure 6). The belt was switched to return airflow and the return entry was converted into a secondary intake. This enabled 62 m^3/s (131,000 cfm) to reach the headgate end of the longwall face rather than 50 m^3/s (106,000 cfm) before the switch (Figure 7). The methane emissions from the solid coal rib of the converted return entry are now coursed to the longwall face. The higher air quantity outweighed this added methane loading.

Entry Resistance

Entry resistance plays a significant role in determining how much air is delivered to the last open crosscut. By doubling the resistance of the entries, the expected flow rate should decrease to approximately 71% of the original airflow.

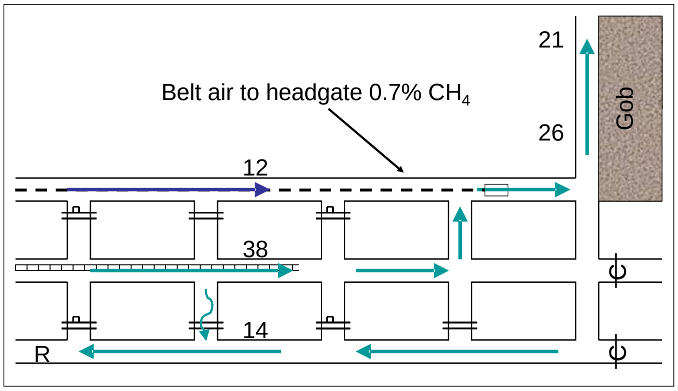

Figure 6. 4270-m longwall panel at startup with belt air.

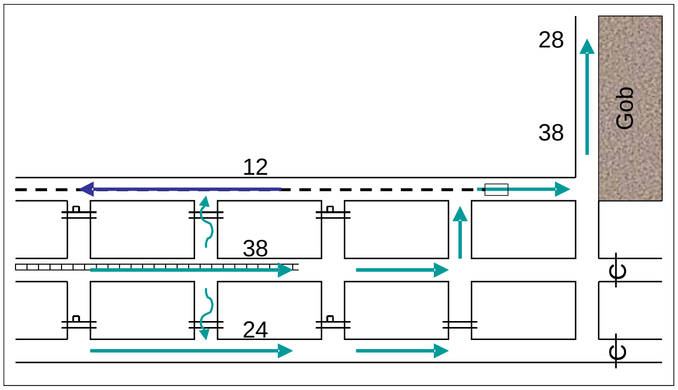

Figure 7. 4270-m longwall panel at startup with dual intakes.

$$Q \propto \sqrt{\frac{P}{R}}$$

In the ventilation models, the stopping resistances are kept constant and therefore the system will have a higher leakage percentage. The above simplification will only hold true if stopping resistance also increases by the same ratio as the entries' resistances. With the stopping resistances kept constant and the entries' resistances doubled, the calculated airflow at the last open crosscut can be reduced to less than 50% of the base case.

CASE STUDY

A three-entry longwall panel was converted from using belt air on intake to return for gateroad development on subsequent panels. The mine indicated that everything was kept the same in the development of the two adjacent gateroads except for reversing the airflow in the belt and the higher pressure at the mouth of the section of the new gateroad. This conversion was possible because the mine had just connected to a new ventilation shaft. The initial measured airflow distribution is shown in Figure 8. The gateroad was 3670 m (14,000 ft) in length and had 65 crosscuts. The layout placed the belt in #1 entry, the intake in #2, and the return in #3. The supplied airflow to the last open crosscut was 26 m^3/s (55,000 cfm), with leakage from the intake entry into the belt entry. While there was still more airflow in the intake for the last 600 m (1970 ft), the 3600-m (11,800 ft) ventilation model showed that belt air may have been leaking into the track entry (as previously shown in Figure 4).

The individual stopping resistances utilized were chosen to be 3500 Ns^2/m^8 (313 x10^{-10} in·min^2/ft^6) using a 3600-m (11,800 ft) VnetPC ventilation model constructed before. The modeled airflow pattern corresponds closely with Figure that represents both the measured airflow patterns of the actual 3670-m (12,000 ft) gateroad and the 3600-m (11,800 ft) ventilation model. The second ventilation model of the gateroad shows the same 3600-m (11,800 ft) ventilation model gateroad but with the belt on return (Figure 9). The airflow at the last open crosscut reduced from 26 m^3/s to 16 m^3/s (55,000 cfm to 34,000 cfm). To deliver original airflow of 26 m^3/s (55,000 cfm) to the last open crosscut, the pressure differential at the mouth of the section had to be increased to 1010 Pa from 432 Pa (4.1 from 1.8 in w.g.).

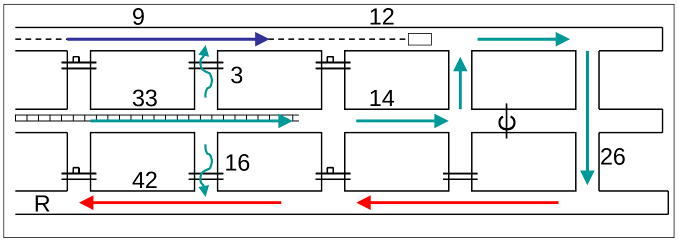

Figure 8. 3670-m gateroad with belt air on intake, plus 3600-m ventilation model (432 Pa).

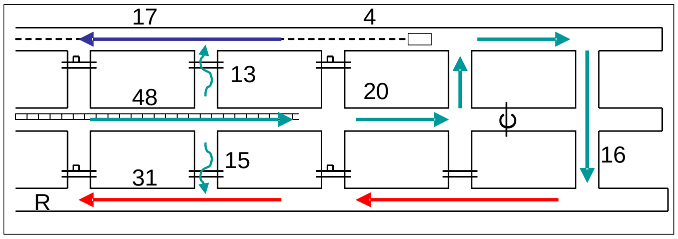

Figure 9. 3600-m ventilation model with belt on return (432 Pa).

Figure 10 shows modeled airflows with a pressure differential of 1010 Pa at the section mouth and stopping resistances of 3500 Ns^2/m^8 (313 x10^{-10} in·min^2/ft^6) , 26 m^3/s (55,000 cfm) at the last open crosscut, and the belt entry outby. There is too much leakage in Figure to match the field-measured airflow distribution pattern shown in Figure 11. Modeled stopping resistances were increased to 5000 Ns^2/m^8 (448 x10^{-10} in·min^2/ft^6) to better match the actual airflow pattern after resealing the stoppings as shown in Figure 12. The mine site was contacted again and the authors were told that a second sealant coat was applied to the stoppings months after installation to reduce the air leakage that occurred because of the higher pressures and stopping deterioration. The stoppings were constructed using the same material but the higher pressures and leakage necessitated resealing.

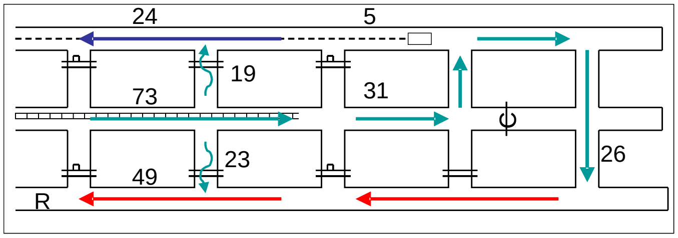

Figure 10. 3600-m ventilation model pressure requirements to supply 26 m^3/s at the last open crosscut using original stopping resistances of 3500 Ns^2/m^8 (1010 Pa).

In this case study, converting the belt entry to return increased the pressure and airflow requirement from 42 m^3/s @ 432 Pa (89,000 cfm @ 1.8 in w.g.) to 62 m^3/s @ 835 Pa (131,000 @ 3.4 in w.g.) at the mouth of the section. This calculates to a 185% increase in static air power (Quantity x Pressure) to ventilate the same length gateroad. If the original stoppings were not resealed, the static air power would have increased 306% (73 m^3/s @ 1010 Pa) (155,000 cfm @ 4.1 in w.g.). Higher pressure requirements at the mouth of the gateroads will also result in higher leakages in the mains and submains and a further increase in pressure on the total mine ventilation system.

Belt in middle entry for very long gateroad developments

If an ideal three-entry gateroad is developed with equivalent resistances in all entries, no stopping leakage, intake air supplied through the belt entry, and with the airflow evenly split between the two intake entries, 80% of the head loss will occur in the return entry. The same holds true for a single intake entry with two return entries. This physical limitation of three-entry gateroads is the real restrictive factor in their development – no matter which choice, one entry will end up carrying the entire section airflow and have high head loss.

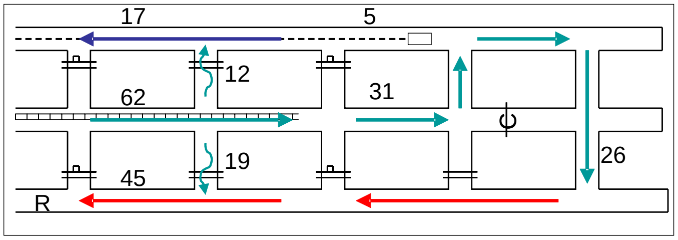

Figure 11. 3670-m gateroad with belt on return, better stoppings.

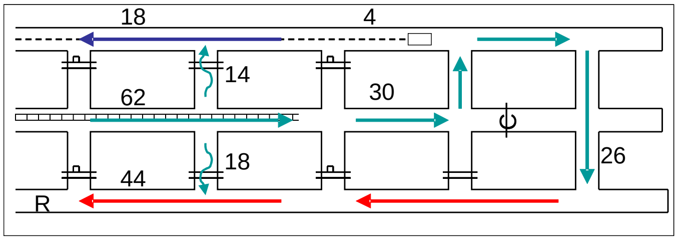

Figure 12. 3600-m ventilation model with belt on return, better stoppings (835 Pa).

For example, consider a three-entry gateroad where Q m^3/s is brought up both the belt and intake entries. The return is required to remove 2Q. The head loss is = $RQ^2 + R(2Q)^2 = 5\ RQ^2$. Alternately a four-entry system with two intakes would move Q each and the two returns would also remove Q each. The head loss is = $RQ^2 + RQ^2 = 2\ RQ^2$ or 40% of the head loss compared to the three-entry example. A four-entry system could, therefore, theoretically develop a greater distance because of more airflow can be moved with less pressure and less leakage by the shared entries. This is the case for gaseous longwall operations choosing four-entry gateroads.

An alternative way to develop very long gateroads is to place the belt in a middle entry as a low airflow belt outby entry or belt air to the working section entry (Figure 13). There is no difference to the quantity of airflow reaching the last open crosscut if the middle belt is operated on belt air or outby. The leakage into the belt from the intake entry will closely match the leakage from the belt to the return. One leakage path from the intake is eliminated and air leaking from the intake to the return has to pass through two sets of stoppings. Airflow would have to pass through a stopping to move from the intake into the middle belt entry and then pass through a second stopping to reach the return. There is no theoretical limit on development length when using the belt in the middle entry (Figure 14), just a practical limitation. The 'Belt Middle' designation is the example of the belt located in the middle entry ventilating airflow to the working section. The belt would have to be moved over to an outer entry after development before longwall panel extraction could commence. This is a costly and time consuming process but would allow for the development of extremely long gateroads. The final use of the gateroad to ventilate the longwall panel and bleeder system should also be evaluated. A longwall operation using a four-entry yield-stiff-yield pillar layout developed the gateroads with the belt in the #2 entry and then used the shearer to mine the yield pillar during panel extraction.

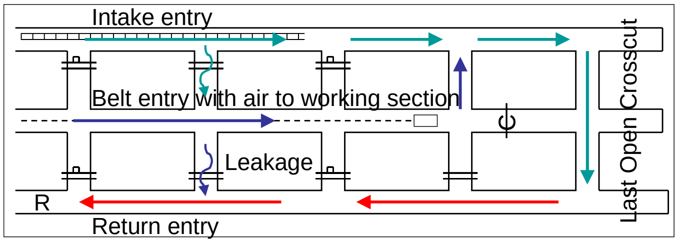

Figure 13. Belt in middle entry on intake.

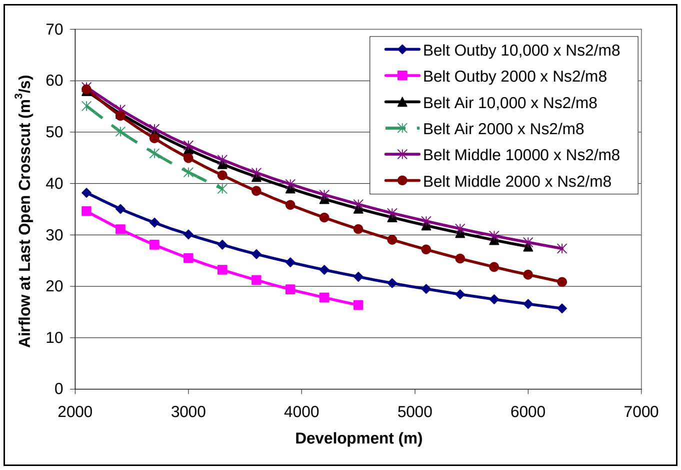

Figure 14. Airflow at last open crosscut for different belt locations (#1 entry or #2 middle entry), belt air used to ventilate the working section or belt outby, and for different stopping resistances Ns^2/m^8.

SUMMARY

The use of belt air to ventilate the working section during gateroad development can increase the total airflow at the last open crosscut but with possible disadvantages. The physical ability to move more airflow to the last open crosscut can outweigh the added methane emission from the solid coal rib so long as it is not displacing fresh intake air. For long gateroad distances or poor stopping resistances, there could be situations where the belt air leaks into the intake entry. When belt air starts leaking into the primary intake, the major concern is that a belt fire will contaminate the intake air split with CO and smoke and make escape more difficult. This paper showed that ventilation pressure at the section mouth and stopping resistances are the limiting considerations for the maximum length gateroads that can be developed using intake belt air. In a case study a three-entry gateroad that converted from belt air ventilating the working section to belt airflow outby the working section increased the air power requirements at the mouth of the gateroad 185% to maintain the same airflow at the last open crosscut.

DISCLOSURE

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

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