13th United States/North American Mine Ventilation Symposium, 2010 – Hardcastle & McKinnon (Eds.)

Booster Fans – Some Considerations for their Usage in Underground Coal Mines

S. Gillies & C. Slaughter
Missouri University of Science and Technology, Rolla, MO, USA

F. Calizaya
University of Utah, Salt Lake City, Utah, USA

Hsin Wei Wu
Gillies Wu Mining Technology Pty Ltd, Brisbane, Queensland, Australia

ABSTRACT: A booster fan is an underground fan installed in series with a main surface fan and used to boost the air pressure of the ventilation air passing through it. Currently booster fans are used in several coal mining countries including the United Kingdom, Australia, South Africa and China. In the US they are used in several metal and non-metal mines however, due to concerns of uncontrolled recirculation, coal mine operators have not been allowed to use them. This paper presents some design considerations pertaining to installations where booster fans are in use in non-US underground coal mines and which are achieving safe and efficient atmospheric conditions. They are found in high and low gas conditions and on occasions where workings are located at great depths (greater than 1000 m below surface). Booster fan installations may be found in Mains ventilation headings where they influence flow throughout the mine, in Section headings where influence is principally on one working face or where they allow for recirculation of uncontaminated return air into the intake. Booster fans are designed with interlocking systems to control, for instance, underground fans and avoid recirculation when surface fans are unexpectedly turned off. Mine atmospheric monitoring systems are in common use. A study is described that has objectives to investigate considerations relevant to operation of booster fans safely and efficiently in underground coal mines within the context of US mining. The study is current and details and some results from the work plan are discussed.

1 Introduction

In some western U.S. mines, coal is extracted from seams covered with more than 1,000 m of overburden. At these depths coal mining has encountered challenges from ground control and ventilation. The development of three or more entries has resulted in intersection failures, rib falls, and frequent bumps. These problems have contributed to reductions in the cross-sectional area of main airways, with a consequent increase in resistance to air flow. At the same time, with increased depth, the gas emission and heat flow rates have also increased, requiring larger quantities of fresh air. In some mines, belt air entries have been used to supply additional amounts of air to active workings. However in many cases as described by Calizaya (2009) high pressure booster fans are used to supply these quantities. Higher pressure fans often induce large losses through leakage of fresh air and create unsafe conditions. Booster fans can be used to assist main fans in overcoming these adverse conditions.

A study being undertaken by the University of Utah and the Missouri University of Science and Technology (Missouri S&T) has objectives to investigate the conditions under which booster fans can be used safely and efficiently in underground coal mines. Specifically, the study is directed at:

- when booster fans become a more attractive and economically viable solution in coal mines due to increases in air requirements at higher production rates, increases in extent and depth of workings and the situation where mines are being developed under environmentally sensitive areas,
- collecting reliable information on airway resistances and flow requirements typical in large US coal mines,
- collecting fan performance data typical in US coal mines where the use of booster fans could be contemplated,
- monitoring the performance of booster fans in a laboratory model and an experimental mine,
- developing a booster fan selection method to assist the ventilation engineer at the planning stage.

The utilization of modern booster fans started in the United Kingdom in the early 1900's when it was reported that booster fans were used to ventilate three separate coal seams at the Hulton Colliery. The UK Coal Mine Act of

1911 allowed British coal mines to use booster fans provided that there was a main fan on the surface. As a result many underground booster fans were installed and work conditions improved substantially. This was demonstrated by a drop in British fatal explosions from 23 in 1911 to 6 in 1919 (Saxton, 1986).

A review of the current literature in mine ventilation shows numerous examples of the utilization of booster fans in the UK. Burnett and Mitchell (1988) is one such example. The Wearmouth colliery (Robinson 1987) is another such examples. In this mine, the active workings were at distances of more than 11 km from the access shafts. The ventilation system consisted of two main intake slopes and one return shaft. The air was directed to the workings by means of one surface fan and three booster fans with a combined capacity of 236 m^3/s. One of the booster fans extracted 99 m^3/s of air at 5,000 Pa pressure.

In 1986 the Alabama coal operator Jim Walter Resources Inc. submitted a petition to the Mine Safety Health and Safety Administration (MSHA) to operate an underground booster fan at its No. 7 mine. The plan specified a Jeffrey fan equipped with a 746 kW direct drive motor located in the main intake. The projected fan capacity was 330 m^3/s at 2,000 Pa. The proposal was rejected mainly due to the potential for flow recirculation through the fan. The proposal was revised to eliminate the danger of flow recirculation, the fan capacity decreased to 154 m^3/s at 1,075 Pa (298 kW), gas detectors made available, and resubmitted to MSHA in 1987 (Sartain and Stevenson, 1989). Two years later the proposal was rejected mainly due to lack of expertise in the mining industry to evaluate the performance of these fans.

2 Utilization of Booster Fans

The use of booster fans to assist in the ventilation of either individual panels or the entire mine is not common in coal mines due, normally, to the ease of installing additional shafts or larger surface fans compared to the operational problems and cost associated with installation of underground booster fans. However, with significant increases in volumetric requirements at higher production rates, increase in block geometry and depth of workings together with mines being developed under environmentally sensitive areas, booster fans become a more attractive and economically viable solution. Currently, booster fans are used in several coal mines located in the United Kingdom, Poland, and Australia (Jobling et al, 2001).

A booster fan is an underground ventilation device installed in the main airstream (intake or return) to handle the quantity of air circulated by one or more working districts (McPherson, 1993). It is installed to operate in series with a main fan and boost the air pressure of the ventilation air passing through it. To accomplish this objective, the fan is installed in a permanent stopping and equipped with airlock doors, interlocking devices between main and booster fan controls, and a monitoring system to assess continuously the operating conditions of the fan.

The purpose of booster fans is to overcome a fraction of the mine’s frictional losses in a similar manner to surface fans overcoming all losses within a mine. Booster fans may, for example, be located in individual gate road(s) to boost panels or in main return headings to boost the entire mine circuit. It is the second application that is likely to become more common.

Some of possible advantages of booster fans identified are:

- reduced intake to return pressure differentials and hence reduced leakage and need for airlocks;
- reduced surface fan pressures, allowing existing installations to remain in place;
- as an alternative to avoid potentially more expensive options such as shafts, additional headings or prohibitively large surface fans; and
- as a method to be used to boost single panel(s) rather than the whole mine to minimise regulation and hence mine resistance.

Use of booster fans can lead to lower operating electricity power costs as they augment mine fan power and do not destroy energy as occurs with use of mine regulators. As such they are a better alternative approach to balancing or controlling airflow through mine parallel splits. They may extend life of mine fan duty as they augment mine fan power. Their introduction allows deferral of installation of a new ventilation shaft or other major capital facility.

However there are various disadvantages of booster fans:

- Capital cost of booster fans will certainly be greater than cost of regulator installation.
- Monitoring of their off/on status is required particularly in gassy atmospheres. Automatic shut off is required if the main fans stop to avoid underground recirculation.
- Shut off of either main surface or booster fans can trigger a requirement of withdrawal of all miners to the surface whether the shut off is caused by an electronic fault or a serious system failure.
- Their use in a gassy atmosphere may require flame-proof electrics or placement of electric motors in intake air. This may necessitate use of extended drive shafts from intake to return air sides of a bulkhead.
- If used in a gassy atmosphere the fan must be designed with anti-sparking characteristics. This means using stainless steel rotor and blades and that the most commonly used axial fan impeller material, aluminum, cannot be used.
- The layout of parallel intake and return airways in collieries does not usually lend itself to the use of boosters. Most colliery panels comprise multiple intake airways and multiple returns in parallel. If one fan is used all return air to be boosted must be directed to one single airway.

- Colliery roadways are usually wide openings with limited vertical dimensions. This shape does not lend itself to the accommodation of a large fan and therefore, a considerable amount of site preparation and removal of roof material is usually required.
- Competent stoppings are required where high air pressures occur downstream of fans to reduce leakage of return air into intakes and avoid recirculating flows.

In the event of some emergency situations such as an underground fire or serious roof fall, it may become critical to control the fan. This requires remote surface control equipment. There must also be proper warning devices on the surface to indicate a stoppage of the booster fan

The practice of using underground boosters is quite common in Australian metal mines but their use in modern collieries has been very limited. The Darkes Forest NSW Colliery made use of an underground booster fan installation in the 1970s. New applications have occurred in Australian coal mines with installation of booster fans utilized in Australian mines as an integral part of the mine ventilation system. Two coal mines have seven to eight years of booster fan usage experience each although one of these has recently decommissioned its installation due to that availability of air from a new shaft. A third mine under sensitive forest land is in the process of installing a set of booster fans while a fourth is seriously considering an installation due to requirements for dilution of high gas levels.

Other booster fan installations are under serious consideration in Australia. Booster fans have been common in use in Europe particularly in the working of very deep seams. It is in this context that the banning of their use in US coal mines is being examined.

Use of booster fans can overcome some major ventilation problems and provide extremely important advantages. It should be recognized that boosters have a number of disadvantages particularly in the coal mine environment. Sometime into the ventilation life of a mine it is quite common that the duty point of the surface fan lies near the unstable portion of its characteristic. If the ventilation requirements cannot be satisfied, the following factors must then be examined.

Whether the fan performance, particularly its pressure capability can be increased and if so, what power increase would result. A completely new primary fan may be necessary.

The feasibility of an additional ventilation shaft or additional underground airways may have to be considered.

Either alternative is likely to involve considerable capital expenditure and/or may be impracticable. Under such circumstances, it is very likely that a booster fan would be a viable cost-effective solution. The key factor, which is not always apparent to the mine operators, is that the artificial restrictions or regulators in the ventilation system increase the pressure necessary to generate the total flow.

In one Australian situation a booster fan installation was placed in each of two headings in the Mains returns in parallel. This installation was justified on the basis of moving the longwall operations to a new district with set ventilation requirements over the life of the new district. The current ventilation system was unable to satisfy the future ventilation requirements and hence booster fans were considered and implemented (Benson, 2001). This mine currently operates four underground booster fans to increase air power to inbye locations of the mine (Ashelford, 2009).

The use of booster fans in underground mines can be divided into three categories: fans in the mains returns, fans in the panel returns and fans that allow for recirculation of uncontaminated return air into the intake. Of the systems studied, the most prevalent is the use of booster fans in the main returns.

The installation of booster fans in the main returns of coal mines poses several unique challenges. The first and foremost is installing fans in such a way that methane in the returns does not pose an explosion hazard. The simplest solution would be to install the fan with an explosion-proof motor. This however is not an optimal solution due to the cost of the motors. Another solution would be to situate the fans such that a system of belts and drive shafts will be used to transfer power from the motor located in the intake airway to the fan located in the return entries. In an example of this system with three primary exhaust returns available mine booster fans were installed in bulkheads in two of the return entries with a by-pass door installed in the center entry. The drive shafts were run through the bulkheads in the crosscuts next to the fans so that the motors could be installed in areas of intake air. Another solution to the problem of methane ignition would be the use of non-sparking motors that are either compressed air driven or hydraulically driven. These methods of powering fans are usually limited to smaller auxiliary fans intended for face ventilation.

The use of booster fans to assist in panel ventilation is less widespread. Only one coal example is known from the literature (Ashelford, 2009); however in metal and nonmetal mines booster fans are quite common. In general these installations are similar to installations in the mains with the fans situated in the return airways and the motors placed on the other side of the bulkheads in the intake airways.

The final example of booster fan installations are those that are seen in controlled recirculation. The primary examples of this method are in collieries in Britain. While generally prohibited, this practice has been allowed on a case by case basis. These systems are used in mines where the surface fan can meet the statutory ventilation requirements, the mine is non-gassy and additional airflow is desired at the face to reduce dust, heat or other environmental nuisances. These systems are primarily located in a small drift driven next to the intake that is connected through a series of overcasts to the primary exhaust airways. Monitoring is done both in the return before the recirculation split as well as after the recirculation split in the intake. The monitoring systems are preset so that if methane or carbon monoxide levels increase in the recirculation split increase the recirculation fan will shut down automatically.

At a point in the mines life where the main fans are operating close to their stall point or an unstable region of the operating curve several options must be considered to prolong the operation's life or provide the option to extend workings into new areas. This includes consideration of the ability to increase the duty of the main fan installation with an associated increase in power consumption, whether new main fans are required or use of additional ventilation infrastructure such as a new shaft or an increased number of roadways underground. Each of these options can be assessed in terms of required capital and operating revenues. At this point booster fans can be considered and have in reality been used to extend the life of longwall operations as exampled in the British longwall mining industry (Jobling et al, 2001).

It should also be considered that the use of regulation in longwall operations represents significant additional cost to that required to actually satisfy ventilation requirements. This can be seen by considering the following example adapted from Carruthers et al. (1993). The following assumed conditions exist in a longwall operation:

- Flow through the high resistance district - 95 m^3/s
- Pressure loss in the high resistance district - 1.37 kPa
- Flow through other parallel circuits – 142 m^3/s
- Pressure loss in the other parallel circuits if unrestricted - 0.62 kPa
- Artificial restriction - 0.75 kPa
- Pressure loss of the main intake and return airways - 0.38kPa
- Surface fan duty with no booster fan – 237 m^3/s @1.75 kPa
- Total power requirement with all 237 m^3/s being artificially restricted and fan efficiency of 75% - 554 kW

If a booster fan was installed in the high resistance path and the regulators in the low resistance paths were removed then the new fan duties and power requirements would be:

- Main fan – 237 m^3/s @ 1.0 kPa = 313 kW
- Booster fan – 95 m^3/s @ 0.75 kPa = 94 kW

The total being 407 kW or a power saving of 147 kW. Assuming a power cost of \$0.05/kWh this represents an annual power saving of approximately \$64,000. It can be seen that based on the operating costs that booster fan utilisation can result in power cost savings.

At this point it is then necessary to consider the capital costs of the installation and the controls necessary to minimize induced risks such as local recirculation. Due to the more even pressure distribution within the ventilation system there may be a resultant increased level of overall safety through spontaneous combustion risk management. The savings identified would actually be increased due to reduced pressure differentials applied to ventilation appliances in the network and hence less leakage would be experienced.

It should also be recognized that with booster fan installations monitoring and control of each installation must be maintained at the surface and that the necessary operating procedures must exist including interlocking of all the mine fans. There also exists the need for site preparation to minimize the local recirculation hazard.

In the US the use of booster fans in coal mines is prohibited based on a fear that the operation of a booster fan installation could not be adequately controlled from outside the mine and could lead to abnormal recirculation conditions or other potential hazardous situations (Kennedy, 1999).

It can be seen that with the use of available technologies booster fan installations have been operated in a controlled and safe manner, as can be seen in Britain and Australia, and that such legislative restrictions could force the closure of sub economic operations. The use of booster fans has far greater savings than those demonstrated in the above example if their use facilitates the continued operation of an operation that is being considered for closure. These factors should be considered as part of a complete economic assessment of existing or proposed ventilation designs.

3 Steps in Considering Introduction of Booster Fans

Before the use of any booster fan is considered, alternate options should be evaluated. Options such as upgrading the main fan, repairing damaged bulkheads, and slashing/widening high resistance airways should be considered first, then the possibility of using booster fans. In existing mines, evaluation of the use of booster fans involves four major steps: planning, fan selection, installation, and commissioning.

3.1 Planning

Planning for the use of these fans almost always starts with ventilation surveys and estimation of airflow requirements. This is followed by network modeling and simulation exercises for different ventilation strategies. Optimization procedures such as those developed at the University of California, Berkeley, and the University of Nottingham can be used to this purpose and feasible solutions generated (Calizaya, et al, 1987; Moll and Lowndes, 1994). Furthermore, these can be used to size fans and predict future requirements. However, the simulation results should be checked against practical constrains such as the need of driving bypass drifts, slashing existing drifts, and installing airlock doors.

3.2 Fan Selection

Once the fan duties are specified, the next step is to determine the type, size, and number of fans for the system. Here the objective is to select a fan or set of fans that meets the flow requirements and has high efficiency. There are two basic types of booster fan installations: cluster fans and custom built fans (Burrell and Bennett, 1995). Cluster fans consist of several small axial fans installed in series or parallel arrangements. They are reasonably cheap and readily available. They have a common problem, which is their low efficiencies, usually less than 60 percent. On the other hand, custom built fans are designed to develop the required pressures at high efficiencies (greater than 80 percent) for a wide range of flow rates. They are equipped with inlet and outlet cones, fixed guide vanes, and self closing doors. They can be of axial flow, radial flow, or mixed flow type. To reduce leakage and recirculation, they are installed in concrete bulkheads and equipped with fan condition monitors. Usually, they have higher capital cost than the cluster fans, but reasonably low operating costs for the same fan capacity.

3.3 Fan Installation

Following the fan selection, the next task is site preparation and fan installation. This may require the development of a bypass drift, widening of an existing drift, installation of airlock doors, and miscellaneous civil constructions. The drifts should be widened as recommended by the fan manufacturer. They should provide ample space to house the fan assembly, an overhead monorail, mandoors, and fan condition monitoring components. The fan installation usually starts with the construction of concrete foundations. This is followed with the installation of an overhead monorail, the installation of fan housing and the construction of a bulkhead. The job is completed with the installation of airlock doors and a pre-fabricated fixture between the diffuser and the bulkhead.

3.4 Fan Initiation

The next task is fan testing and commissioning. Testing involves checking the fan for stability, and running it first at no load (with the airlock doors open), and then at full load (with the doors closed). Parameters such as vibration, bearing temperature, shaft alignment, and blade tip clearance are measured during each test. These values are then compared against standards and pre-established limits.

During testing, the following standards are often used: fan vibration: 0.5 mm/s; motor temperature: 85ºC; shaft alignment: 0.05 mm; and fan duty: ± 5% of designed values. The fan is commissioned only when the measured parameters are consistently lower than the pre-established limits (Snaith 1998).

4 Potential Issues

Inadequate booster fan selection or installation introduces potential hazards including an increased likelihood of mine fires and recirculation of contaminants. In the history of utilization of booster fans two major incidents that claimed lives are commonly reported: the Auchengeich Colliery fire in Scotland (1959), and the Sunshine Mine fire in Idaho (1972). In the first case, the belt drive on the booster fan caught fire. The fire spread to the roadway timber and claimed the lives of 43 workers. The workers died from carbon monoxide poisoning. Since then, the use of vee-belt drives in underground mines has been severely restricted (Robinson 1989).

In the second case, the mine, a silver mine, was ventilated by four booster fans installed in series. According to the US Bureau of Mines, the probable cause of the fire was spontaneous combustion of scrap timber used to backfill worked-out stopes. By the time the fire was detected, the smoke had already filled the main haulage way (3700 level) and the intake raises and active stopes located on lower levels (4000-5200 levels). The fans contributed to the rapid propagation of smoke into the workings inbye the fire. Among other factors for this incident were: failure to provide the fans with remote control, failure to monitor the mine atmosphere for carbon monoxide, and delay in starting the evacuation of personnel. As a result, 91 men died of CO poisoning (Jarret, 1972).

5 Significance of this Study

This study steps will include the following:

1. To conduct ventilation surveys in at least two deep and/or extensive U.S. coal mines, and determine the fan duties, airway resistances, and the airflow distribution in the mine. In addition to pressure/ quantity measurements, the surveys will include gas/ dust sampling, and temperature measurements.
2. To conduct ventilation surveys in two existing non-US coal mines where booster fans are used regularly. Plans will be developed to visit at least one of the UK collieries and one of the Australian installations.
3. To install a 15 kW booster fan system at the Missouri S&T Experimental Mine in Rolla. In addition to a 15 kW fan, the system will include various monitors to measure both environmental factors (carbon monoxide, smoke and air velocity) and fan operating factors (pressure, fan vibration and motor and bearing temperatures). The collected data will be used to determine the effect of these factors on the safe operation of the fan.
4. To conduct air pressure/ quantity surveys at the University of Utah's coal mine ventilation model. To this purpose, the model will be upgraded to include a booster fan, a "gob" chamber, a set of regulators and a monitoring system. The collected data will be used to determine the critical parameter(s) to avoid unwanted recirculation.

5. To develop a fan selection algorithm for underground coal mines. For a mine of given geometry, with a possible set of fan locations, the algorithm will determine the design parameters for the safe operation of both main and booster fans.
6. To summarize the basic requirements for the safe operation of booster fans. This will include a summary of standards and regulations adopted by other coal mining countries, applicable standards used in US metal/ nonmetal mines, and rules of good practice for the fail-safe operation of these fans.

6 Fan Selection Procedure

The procedure applied in this study is the one developed at the University of California, Berkeley. This is an empirical approach which, by using a ventilation simulator, allows optimization of a power consumption function subject to a set of linear relationships between fan pressures and regulator resistances. Here, it is assumed that the ventilation system consists of a network of airways, a number of working areas with fixed airflow requirements, and a set of main fans of unknown pressures.

For a two fan system, one main fan and one booster fan, this procedure can be summarized by the following two routines:

6.1 Single Fan System

The process is initiated by assigning a trial pressure to this fan, solving the network for airflow rates and pressure drops, and evaluating the resulting regulator resistances. These resistances are arranged in decreasing order of magnitude and evaluated by applying the following criteria:

- If the smallest resistance is positive, then the fan is oversized. To achieve an improved condition, the trial pressure should be decreased by a fixed amount and the process repeated.
- If the smallest resistance is negative, then the fan pressure is inadequate. This should be increased by a fixed amount and the process repeated to achieve an improved condition.
- If the smallest resistance is equal to zero, then the trial pressure is the lowest fan pressure that minimizes the input power requirement.

In most cases, the solution to the problem can be achieved after three iterations.

6.2 Two Fan System

At this stage, the single fan system is modified to include a booster fan. The network is then solved for the best combination of fan pressures. The procedure is initiated by assigning a fixed pressure to the booster fan and varying the main fan pressure for a given range. For every pair of fan pressures the network is solved for flow rates, pressure drops, and a set of regulator resistances. By applying the evaluation criteria described previously, a local optimal solution to the problem can be determined. The total power consumed by the two fans can be calculated at this stage.

The procedure is repeated for other booster fan pressures and a set of local optimal locations determined. These results can then be plotted as pressure-power graphs, and used to determine the global solution to the problem, namely a pair of fan pressures that satisfies the air flow requirements at the workings and minimizes the total power consumption.

For large networks this procedure can be quite time consuming and complex, especially for networks with multiple surface fans. A more robust and efficient approach to these types of problems will be sought in this project.

7 Booster Fan Project Activity: Literature Review

The study being undertaken by the University of Utah and Missouri S&T has a prime objective of undertaking an up to date literature review. In 1985, The University of California, Berkeley conducted an extensive survey on the utilization of booster fans. The survey showed that there were 1,252 booster fan installations in 758 mines distributed in 13 countries. This information will be updated and other relevant publications on the use of booster fan reviewed.

The University of Utah is collecting documents from the United States and Canada and the Missouri S&T is reviewing international articles including those from the UK, Australia and South Africa. University of Utah documents have been organized into five categories: general booster fan information, coal mine ventilation, sealings and leakage, fan optimization, and fan monitoring. A summary of each category is as follows:

- <u>General Booster Fan Information:</u> Booster fans are in use in hard rock mines all over the world. Articles concerning the installation, operation and maintenance of booster fans in hard rock mines are located in this section.
- <u>Coal Mine Ventilation:</u> Coal mines have specific ventilation requirements that are enforced by MSHA in the US. A number of mines in the past have petitioned MSHA to install a booster fan in their mine, and all recent inquiries have been denied.
- <u>Leakage Through Stoppings and Seals:</u> A booster fan can help reduce leakage across stoppings and seals by reducing the pressure differential across them. A number of studies have been conducted to characterize leakage flow through stoppings and seals. Currently research is being conducted to characterize the amount of leakage flow through stoppings and seals around main fans in coal mines.
- <u>Fan Optimization:</u> Computer programs have been developed and are used to model the ventilation air velocities and quantities across the working faces. Economic analyses of the benefits of different fan

sizes, location and speeds are regularly performed to determine the optimum ventilation system.

- Fan Monitoring: Coal mines primarily monitor CH_4, H_2S, O_2 and CO. Continual monitoring of mine conditions is often carried out through an Atmospheric Monitoring System (AMS). As technology advances, real-time data of conditions in the mine is possible. Wireless tracking systems are becoming more readily available in conjunction with AMS.

Missouri S&T researchers are in parallel currently working on comprehensive literature reviews of international practices regarding booster fans and have been focusing on coal literature. There are numerous coal mines globally that rely on booster fans to ensure adequate ventilation. The current focus is on Australia and the United Kingdom. A summary of each category is as follows:

- Conference Publications: Sources of papers have been from some International Mine Ventilation Congresses and North American Mine Ventilation Symposia.
- Mine information: The majority have come from individual mine reports, plans and conference presentations.
- Government Regulations: Countries and states containing mines using booster fans have various accessible regulation listings and other supporting documents.

At both universities hard copy of each article is stored in a three-ring binder. Digital copies of every article are kept in PDF format, organized in files according to the category. Articles that cannot be located digitally are digitized using a desktop scanner. Using a Microsoft Excel to organize the articles, they can be easily sorted by main author, year of publication, title, and document category.

The initial plans for the mine in relation to this project are the upgrade of the main fan as well as the installation of two booster fans in the underground workings. The booster fans will be installed in bulkheads in a flexible manner so location can be varied during the project. Electronic monitoring systems will be installed to monitor the differential pressures across key stoppings and bulkheads as well as the flow quantity through mine airways. This data will be logged by computer and models will be created to determine optimal placement of booster fans within mine ventilation circuits.

The mine's ventilation system is being analyzed for additional circuits that can be added. Currently using, various shafts throughout the mine, three separate splits of air can be established as shown in Figure 1

A booster fan can be easily established on one of the splits and the immediate effects on varying booster fan settings can be analyzed for their impacts on the other splits within the mine.

8 Booster Fan Project Activity: Experimental Mine Tests

A study being undertaken by the University of Utah and the Missouri S&T has another objective of undertaking ventilation studies with booster fans in use in a controlled mine environment. This is being achieved through use of the Missouri S&T Experimental Mine which is an underground limestone and dolomite mine located just outside Rolla, Missouri. The mine (Figure 1) is accessed by two adits and has three raises to the surface along with the primary ventilation shaft. The two mine portals both have ventilation doors as indicated. Currently, ventilation is provided by a 1.2-m diameter Joy axial vane fan and 30 kW motor set blowing approximately 23.6 m^3/s of airflow at 1,000 Pa of static pressure to the underground workings. The Experimental Mine is used mainly as a teaching laboratory for classes such as surveying, ventilation, drilling and blasting, and mine health and safety. The mine also hosts an annual mine rescue competition every September that draws some 15 teams from around the U.S.

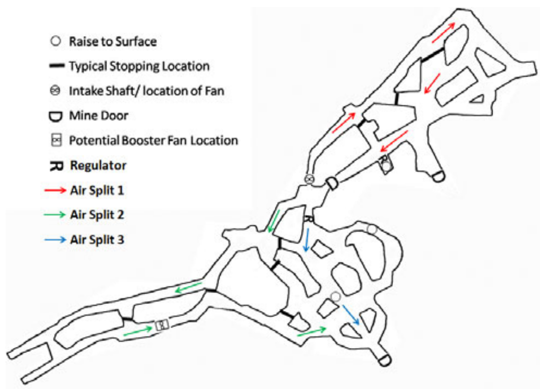

Figure 1 The Missouri S&T Experimental Mine with air splits and proposed booster fan sites highlighted

9 Conclusions

The University of Utah and the Missouri S&T have undertaken the unique challenge of investigating the conditions under which booster fans can be used in US underground coal mines.

This study has the following objectives:

- To conduct ventilation studies in two deep and/or extensive US coal mines, formulate numerical models, and determine their future ventilation requirements.
- To conduct ventilation surveys in two non-U.S. coal mines where booster fans are used regularly.
- To conduct ventilation studies on the utilization of booster fans at the Missouri University of S&T Experimental mine and at the University of Utah's coal mine model.

- To develop an efficient booster fan selection program.

In ventilation planning, flow control devices such as stoppings, overcasts and doors are used to direct the fresh air to active workings and to reduce leakage. These are characterized by a parameter: the leakage path resistance. The magnitude of this parameter varies with on a number of factors including the type of construction materials used, workmanship and maintenance. These factors will be investigated through field measurements, laboratory models and numerical simulators.

Currently, there is no single booster fan selection method that can readily be used by ventilation engineers. Several procedures have been formulated to this purpose. However, these are inefficient, and time consuming. A new fan selection algorithm to produce recirculation-free ventilation designs will be developed. This will enable US coal mine operators to develop ventilation designs to extract coal seams from depths greater than 1,000 m.

Acknowledgements

The authors would like to acknowledge the National Institute for Occupational Safety and Health for providing financial support for this project. We would also like to express our gratitude for Jürgen Brune, NIOSH Office of Mine Safety and Health Research, and Mike Nelson, University of Utah Mining Engineering Department Chair, for their advocacy in developing this project. The authors also acknowledge the assistance of various mine managers and engineers who have supported the study.

References

Ashelford, D., 2009. Remote Operation of Dilution Louvres, PowerPoint presentation, BHP Billiton

Benson, D., 2001. Innovative Fans Boost West Cliff. Australia's Longwalls Sept 2001:20.

Burnett, R.L. and Mitchell, D. 1988. The Safe Use of Controlled Recirculation Techniques in the Ventilations of United Kingdom Coal Mines. Proc. of the 4th International Mine Ventilation Congress.

Burrell, R.A. and Bennett, S.C., 1995. Recent Developments in the Ventilation of Coal Mines. Coal Int., Vol. 243, No. 4, (July): pp. 147–150.

Calizaya, F., McPherson, M.J, and Mousset-Jones, P., 1987. An Algorithm for Selecting the Optimum Combination of Main and Booster Fans in Underground Mines. Proc. of the 3rd U.S. Mine Ventilation Symposium. University Park, PA, pp. 408–417.

Calizaya, F., 2009. Guidelines For Installing and Operating Booster Fans in Underground Mines. Proc of the Ninth International Mine Ventilation Congress, Oxford and IBH New Delhi, Editor, D.C. Panigrahi, Nov 2009 vol 2 pp727-736.

Carruthers, J., Mitchell, P., Savidis, G., Scott, R. & Walker, C. T., 1993. Ventilation. In Hargraves, A. J. & Martin, C. H. (eds), Australasian Coal Mining Practice, 2nd edition, Monograph 12:Chapter 28. Parkville:AusIMM.

Jarrett, S.M., 1972. Final Report of Major Mine fire Disaster – Sunshine Mine. US Bur. of Mines, Health and Safety Report, West. District. I 28.2: H 34/2. Alameda, CA, 174 pp.

Jobling, S., Yates, C., Lowndes, I.S. and Yang, Z.Y., 2001. The Integration Of The Ventilation Networks Of The North Selby and Stillingfleet Mines. In S. Wasilewski (ed.), Proc. Of the 7th International Mine Ventilation Congress, Proc., Krakow, 17-22 June 2001, Katowice:EMAG.

Kennedy, W.R., 1999. Practical Mine Ventilation, 2nd edition. Chicago:Intertec.

Moll, A.T.J., and Lowndes I.S., 1994. An Approach to the Optimization of Multi-fan Ventilation Systems in UK Coal Mines. Journal of the Mine Ventilation Society of S. Afr., (January): Johannesburg.

McPherson, M.J., 1993. Subsurface Ventilation, London: Chapman Hall.

Robinson, R., 1987. Controlled recirculation of air at Wearmouth Colliery, British Coal Corporation. Proc. of the 3rd U.S. Ventilation Symposium. SME, Littleton, CO, pp 1 - 12.

Robinson, R., 1989. The Use of Booster Fans and Recirculation Systems for Environmental Control in British Coal Mines. Proc. of the 4th U.S. Mine Ventilation Symposium. SME, Littleton, CO, pp. 235 - 242.

Sartain, T.L., and Stevenson, J.W., 1989. Jim Walter Resources Inc.'s Booster Fan Proposal – A Case Study. Proc. of the 4th U.S. Mine Ventilation Symposium. SME, Littleton, CO, pp. 363–375.

Saxton, I., 1986. Coal Mine Ventilation from Agricola to the 1980's. Part VIII, Mining Eng., Gullick Dobson Ltd., London, pp. 395–405.

Snaith, J.K., 1998. DOM fan commissioning - Site report 348. Contract Ref. CS 3254, Howden Sirocco PTY, Limited. 97-103 Pacific Highway, North Sydney, NSW, 2060, Aust., 5 pp.