Use of underground booster fans in foreign prominent coal mining countries compared with the ban in the United States

A.D.S. Gillies
Missouri University of Science and Technology, Rolla, Missouri, USA

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

ABSTRACT: Currently booster fans are used in mines in almost all foreign major coal mining countries requiring this form of ventilating air motivation including the United Kingdom, Australia, Poland, South Africa and China. A booster fan is an underground main fan which is installed in series with a main surface fan and used to boost the air pressure of the ventilation to overcome mine resistance. In the United States booster fans are prohibited in coal mines although they are used in many metal and non-metal mines. A detailed study has been undertaken of the usage of booster fans in three coal mines each in Australia and the United Kingdom. The study focused on issues in each mine such as the need for use of booster fans rather than use of additional surface fans, use of gas and airflow quantity and pressure monitoring, potential for air recirculation, reducing leakage, lock out systems in use to handle the situation when some mine fans fail and economic considerations. Regulations in use and the views of mine inspectors have been sought. The approaches in use in Australia and the United Kingdom have been compared in a general way with the situation pertaining in the United States.

1 Introduction

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 almost all foreign major coal mining countries requiring this form of ventilating air motivation including the United Kingdom, Australia, Poland, South Africa and China. In the United States they are used in a significant number of 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 information on design considerations pertaining to installations where booster fans are in use in non-United States underground coal mines and which are achieving safe and efficient atmospheric conditions. In particular use of booster fans in Australia and the United Kingdom is examined. They are found in high and low gas conditions and on occasions where workings are located at greater than 1000 m depths. Booster fan installations may be found in main working districts where they influence flow throughout the mine, in section headings where influence is principally on one working face or where they allow for controlled recirculation of 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 used extensively in all or the mines studied. A study is described that has objectives to investigate considerations relevant to operation of booster fans safely and efficiently in underground coal mines and as a comparison with the situation in United States underground coal mines in which there is a prohibition in usage.

The study has objectives to investigate conditions under which booster fans are being used safely and efficiently in underground coal mines. Specifically, the study is highlighting situations when booster fans become an attractive and economically viable solution in coal mines due to increases in air quantity requirements at higher production rates, increases in extent and depth of workings and the situation where mines are being developed under environmentally sensitive areas.

2 Utilization of Modern Booster Fans

The use of booster fans to assist in the ventilation of either individual mine sections or in the mains to assist 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 challenges and costs associated with installation of underground booster fans. However, with significant increases in volumetric requirements at higher production rates, increases 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. Some of the advantages and disadvantages of use of booster fans have been identified and summarized by Gillies, Calizaya and Slaughter, 2010.

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 six in 1919 (Saxton, 1986). A review of the current literature in mine ventilation shows numerous examples of the utilization of booster fans in the United Kingdom. Burnett and Mitchell (1988) is one such example.

In Australia, booster fans are used in the two underground coal mining states of New South Wales and Queensland. 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 as an integral part of the mine ventilation system. Two coal mines have over eight years of recent booster fan usage experience each although one of these was decommissioned in 2009 due to the availability of air from a new shaft. A third mine under sensitive forest land recently installed a single booster fans in October 2011 while a fourth is seriously considering an installation due to requirements for dilution of high gas levels. Other booster fan installations are under consideration in Australia.

Booster fans have been in use commonly on the continent in Europe particularly in the working of very deep seams. Their use has been significant in multi seam extraction mines with deep and gassy workings such as those found in Poland.

3 Surveys of Booster Fans in Australia and the United Kingdom

Surveys have been undertaken on the use of booster fans in Australia and the United Kingdom. The surveys were undertaken by full day visits to three active mines in Australia and three in the United Kingdom across the period 2010 to 2011.

A common survey sheet and set of questions were used at each of the six mines. The questionnaire contained the following four sections:

1. Section A requested for general information on the mining method
2. Section B sought information on the company's current vent system
3. Section C sought technical information on the installation of booster fans, and
4. Section D requested for the mine operator's perspective on the use of booster fans.

The questionnaire was sent to each mine's manager prior to the mine visit and completed at the mine site. On occasions there were follow up calls to ensure accuracy. The surveys were always completed with the mine ventilation engineer or officer present and generally with others such as the mine electrical engineer and additional senior technical personnel.

Australian and United Kingdom practice is that new coal mine booster fans are installed and commissioned after a period of review that there is no other practical and economic way of effectively ventilating planned production sections. In addition there is a period of exchange with the mines' inspectorate and agreement that certain requirements are met. One of these requirements is that each booster fan must be equipped with a set of continuously operating monitors. Australian underground coal mining practice has in many ways closely followed United Kingdom advances and many approaches to booster fan usage in Australia have followed practices tested and found successful in English mines.

4 Australian Survey

All three of the underground coal mines in Australia which had recently used, were currently using or planned to use booster fans in the near future were visited. Some examples of current practice observed can be briefly summarized as follows:

- The installation of booster fan installations requires a thorough evaluation and risk analysis and a management plan demonstrating adoption of world best practice must be submitted to the state inspectorate. In addition in NSW approval must be given by the mines' inspectorate (under Regulation 91).
- All Australia booster fans are installed in return airways with their motors and some electrical components sited separately and adjacent in intake air. Booster fans are located in the return airways with their motors and electrical components in intake air. For multiple fans, fresh air is directed to the motor room through 300mm diameter pipes.
- The fans are installed in concrete stoppings sprayed from the high pressure side. Double or single inlet centrifugal high pressure fans are in use.
- Australian miners prefer centrifugal fans over axial ones mainly because of their high pressure requirements.
- The possibility of mine fires is the major design parameter. As part of the safety management plan all underground booster fans are equipped with environmental and fan monitors. At each fan, the following parameters are monitored:
    - Methane using electronic monitoring (with alarm system set at 1.25 % CH_4) and tube bundle gas systems,
    - Fan static pressure,
    - Equipment conditions**.**
- There is electrical interlocking between the main fans and the booster fans at all installations. If any monitor fitted to a main fan or booster fan detects a significant departure from normal operating conditions, the monitor must automatically:
    - Activate a visible alarm,

- Trip power to the fan,
- Record details of the event.
- In Australia all main fans, surface and booster fans are maintained at least every four months, with fan clean up every month

5 Some Survey Details

- Mine A has installed one 600 kW centrifugal booster fan passing 170 m^3/s of air at 3 kPa of total pressure to exhaust from two working districts. The fan is installed in a 150 mm thick concrete wall and equipped with environmental and fan monitors. A booster fan approach to maintaining required airflow underground was selected as sinking of a shaft was not possible in an environmentally sensitive area. It is planned to operate the fan for about 5 to 6 years by which time construction of a shaft for ventilation requirements will be possible and receive environmental approval.
- Mine B operates four booster fans each fan with a capacity of 150 170 m^3/s of air at 3 kPa of total pressure. The fans are equipped with environmental and fan monitors controlled from surface. Rigorous risk analyses were completed and reviewed at the chief inspectorate level prior to their installation as they were the first new booster fan investments in Australia for a long period. A booster fan approach to maintaining required airflow underground was selected as construction of a shaft was not possible in an environmentally sensitive area. In addition booster fans have proved to be the most economic solution to maintaining required ventilation in a mine which has been working for a relatively lone period and with extended workings over a large area. The fans are considered as integral part of the mine ventilation system. They are not being considered for replacement; they are a long term investment and it has been stated that “the mine would not be operating today without the fans”.
- Mine C has operated two 400 kW centrifugal booster fans over a recent six years period. The fans operated without any major problems. Booster fan investment occurred as it was deemed at the time to be the most economic approach to maintaining required airflow underground. Recently, the mine ventilation system went through a major upgrade that included the sinking of a new shaft and the installation of larger capacity fans. The fans have been decommissioned.

6 United Kingdom Surveys

Three of the five significant underground coal mines in Britain using booster fans were visited (booster fans are used in all of the significant underground coal mines in that country). There is a long history of booster fan use and some examples of current practice observed in Britain can be briefly summarized as follows:

- Booster fan installations are accepted as a safe and effective means of ventilating sections. In all of the mines visited booster fans were viewed as the only option for providing adequate ventilation underground.
- Both axial and centrifugal fans are found in use with installations in concrete bulkheads. Axial fans are installed in clusters with up to four, two-stage fans per site. Multiple heavy duty airlock doors are in use. A double inlet centrifugal fan is in use in one mine.
- Booster fan sites are equipped with monitors at each fan. Fan parameters included differential pressure, motor and bearing temperatures and air velocity. Environmental parameters included methane, carbon monoxide and smoke.
- Booster fans are more likely to be located in the returns and in series with the main fans. The motors and electrical components are also located in the returns and are enclosed in flame proof housings. There is no electrical interlocking between the main fans and the booster fans at any of the mines visited.
- Recirculation and series ventilation are not strictly prohibited. Although not a common practice, series ventilation is used under extreme circumstances. The booster fan installations are designed to reduce leakage and limit recirculation. It was made clear that on average mines were recirculating about 10 % percent air.
- The United Kingdom inspectorate has a comprehensive system in place for approval of booster fan installations.
    - The use of booster fan in an average well engineered coal mine can only be justified where there is a quantified need for booster fan to ventilate part of a mine i.e., needed for production to provide extra air to dilute extra gas, dust, etc.
    - The mine manager in charge must have done a study; show ventilation situation before introduction of booster fan and show. Study must be based on a pressure-quantity survey and use of ventilation simulation.
    - Report must demonstrate what will happen with introduction of booster fan such as effects of neutral point; recirculation, etc. Management may give economic evaluation but not necessary.
    - Inspectorate then sends to applicant manager conditions for use of booster fans eg redundant power supply, fire detection system, fire suppression

system, doors monitoring, auto restart, gas and air monitoring.

  - Manager must respond with thorough study of these aspects. Study must emphasize system design, installation standards, maintenance and monitoring standards.
  - When booster fan system installed and running inspectorate must visit and check installation, maintenance and monitoring standards. This is a serious approval and inspectorate has power of objection.

7 Some Survey Details

- Mine A employs in excess of 800 persons and is the most significant coal mine in the United Kingdom with an annual output budget in excess of 3 million tonnes and regularly achieving an output rate exceeding 4 million tonnes per annum. Production is achieved through a single longwall face, currently mining at a depth of 800m below the surface and approximately 8km distant from the shafts. The mine has two shafts and a surface drift, all of which are active. Whilst no methane drainage / extraction is employed, significant methane gas levels on the face and return gates can result from gas liberation due to the high production levels being achieved. Spontaneous combustion is an ever present risk, especially during salvage periods. However, spontaneous combustion can occur anywhere and regular events occur during development usually at junction pillars or near some faulting structure where air leakage paths are likely.

  The mine uses two, twin sets of booster fans. Fans are installed in concrete bulkhead above the coal seam to prevent spontaneous combustion. This leads to minimum leakage and recirculation and enables avoidance of travel route. Main and booster fans are interlocked. The mine utilizes two main surface fans at about 2.8 kPa static pressure and two, two stage booster fans at 3.5 kPa pressure difference across the bulkhead. If no booster fans were used, the main fan pressure could be in the order of 13 kPa. Booster fans require use of an increased number of airlock doors.
- Mine B is served by two vertical shafts. No.2 shaft is a downcast shaft and is used for man riding and materials while No.3 shaft is an upcast shaft and is the main coal winding shaft fitted with skips. There is also a third shaft No.1 shaft downcast shaft with no winding facilities. A set of booster fans are installed in the main return roadway to assist the main fan in ventilating the mine. Air velocities are quite high in parts of the mine as inbye coal faces require some 50 m^3/s to maintain a safe working environment. Methane drainage is employed. One booster centrifugal fan with a capacity of 290 m^3/s of flow rate at 7 kPa of pressure is operated in the main return. Its position allows avoidance of being in a travel route and minimizes recirculation and leakage. It reduces potential for spontaneous combustion. Main and booster fans are interlocked.
- Mine C has two main shafts with each almost 800m deep. The downcast shaft is used for the conveyance of men and materials and the upcast shaft is used for the conveyance of mineral. Currently workings are in a 2.6m thick seam at a depth of 750 to 780 m. Further reserves are expected to be accessible in a 2.4m thick seam and should extend the life of mine to around 2019. The mine utilizes one centrifugal surface fan and two sets of axial booster fans. These are placed in return air to avoid travel routes, minimize recirculation and leakage. One of the booster fans has a capacity of 160 m^3/s of flow rate at 7 kPa of static pressure. Spontaneous combustion potential needs to be avoided with high standard leakage control. The booster fans increase flow rate to working areas of the mine above that available otherwise in a cost effective manner.

8 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 widening high resistance airways should be considered first before the possibility of using booster fans. In existing mines, evaluation of the use of booster fans involves planning, fan selection, installation, and commissioning. 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. 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, widening existing drifts, and installing airlock doors.

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. 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, overhead monorail, man-doors and fan condition monitoring components. The fan installation usually starts with the construction of concrete foundations. This is followed with the installation of fan component and construction of a bulkhead. The job is completed with the installation of airlock doors and pre-fabricated fixtures between the diffuser and the bulkhead.

The final 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. Inadequate booster fan selection or installation introduces potential hazards including an increased likelihood of mine fires and recirculation of contaminants.

9 Significance of this Study

This paper has been examining booster fan usage in coal mines and approaches in use in Australia and the United Kingdom against a background of the situation pertaining in the United States. As described by Lauriski and Yang, 2011, United States mine safety regulations have always been prescriptive but have become increasingly so in response to the Sago Mine multi-fatality accident of January 2006. Since then the United States Mine Safety and Health Administration budget, number of citations and assessed penalties for violations has increased dramatically but catastrophic accidents continue to occur. They raise the question why have other countries such as Australia, the United Kingdom and South Africa with large modern coal mining industries achieved better mine safety performances than the United States?

Traditionally Australian mining regulations were also prescriptive. However, since the 1990's, these have shifted to performance and/or risk based measures with the passing of new legislation in the two main states of New South Wales and Queensland. The new legislation is outcome based and embraces the concept of system based standards that incorporate principles of risk management. The legislation was adopted instead of prescriptive or specification standards which tell employers precisely what measures to take, which technologies to use and allow little interpretation. Australia's current safety approaches impose general obligations that require mining industry employers to establish internal health and safety management systems and to continue managing risks as long as it is reasonably "practicable". These have requirements to establish principal hazard management plans for specific hazards that include, among others, strata failure, in-rush, fire and explosions, dust explosions, explosives and airborne dust. Plans required of the mine operator must include standard operating procedures, measures to control risks, triggers of actions and responsibilities. The change of approach in Australia has had a dramatic impact on safety performance. For example from 1997 to 2007 the Australian mining industry average fatal injury frequency rate (FIFR) was 0.07, compared with the United States rate of 0.17. By contrast from 1989 to 1999 Australia only had a slightly better average FIFR than United States mining. Similarly, in South Africa, the Mine Health and Safety Act of 1996 was amended in 1997 to introduce concepts of risk management and requirements for health and safety management.

It is of interest that Australia, the United Kingdom and South Africa have been leaders within the international mining industries to adopting systems of safety risk management. The onus for responsibility is placed with the mine operator who must prove awareness of requirements to achieve operational behaviour at a standard of world's best practice and accept responsibility. Potential hazards that may occur in use of booster fan systems must be assessed under risk management procedures. Systems are not prescriptive but the onus of responsibility requires that all safety issues in a particular situation must be assessed and written safety systems utilized.

In the United States the approach is prescriptive and 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 is in this context that the banning of their use in United States coal mines is being examined. It can be concluded that the United States has fallen behind similar coal mining countries in adopting risk management based safety approaches. As such there is hesitancy by inspectorial groups both federally and within the states to allow use of complex systems such as booster fans as they do not easily lend themselves to regulation through prescriptive systems. Rather complex booster fan systems require "ownership" for safety systems to be accepted by mine managers through a risk management approach.

10 Conclusions

It can be seen that with the use of available technologies booster fan installations have been operated in controlled and safe manner in Australia and the United Kingdom and other major coal mining countries. Legislative restrictions such as restricting use of booster fans could force the closure of sub economic operations. The use of booster fans has far greater savings than those demonstrated in the Australian and United Kingdom examples if their use facilitates the continued working 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.

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