Breaking the ice on the booster fan dilemma in US underground coal mines

by A.L. Martikainen and C.D. Taylor

Abstract Booster fans increase air pressure to overcome resistance, the objective being to force adequate amounts of air through distant workings. They are used in areas that are difficult or uneconomic to ventilate with main fans alone. Booster fans are currently permitted in underground coal mines in some countries; the United Kingdom, South Africa, Australia and Canada have been defined as major users. Booster fans are not allowed in the US bituminous and lignite coal mining operations at the present time due to safety concerns. This paper presents the history of booster fan use in coal mines of the United States during the last 90 years. Changes in regulations, as well as advantages and disadvantages of booster fan use, are discussed. Research and petitions for booster fan use are highlighted in order to bring the debate into focus.

Introduction

In the United States, booster fans are permitted in metal and nonmetal (M/NM) mining, as well as in anthracite coal mines. Legislation promulgated in 1992 specifically prohibits their use in underground bituminous and lignite coal mines (*Federal Register*, 1992).

Currently, the National Institute for Occupational Safety and Health (NIOSH) is beginning a new research program that will include an investigation of booster fan use as an alternative to using the belt entry to supply ventilation airflow to production faces. The aim of this paper is to present a historical review of past experience with booster fans and discuss the safety concerns and issues that may affect their use in the future.

Martikainen is a research engineer and C.D. Taylor is an industrial hygienist at the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA. **Paper number TP-09-030. Original manuscript submitted June 2009. Revised manuscript accepted for publication May 2010. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications by Jan. 31, 2011.**

First, it is important to understand what a booster fan is and what it is used for. The most often-mentioned attributes that define a booster fan are:

- Installed underground.
- Installed in the main airstream or a split of the main airstream.
- Operates in combination with the main fan(s), even if physically separated.
- Used to balance pressure drops, decrease leakage and/or increase pressure to overcome resistance.
- Handles airflow of either one or several districts of the mine.
- Not used as a face fan to ventilate blind headings.

Some definitions include installation in a permanent stopping or a bulkhead.

Booster fans are used in other countries, as well as in M/NM mines of the U.S., to ventilate distant workings. Installing booster fans is the only alternative to building more surface connections when the usual ways to increase ventilation, such as adding intake and return entries, larger main fans or widening shafts, are considered impractical or uneconomical. A booster fan is typically installed to overcome mine environmental conditions in which the surface fan is physically incapable of meeting the airflow requirements or when these requirements can only be fulfilled at extremely high pressures, which can cause excessive air leakage (Calizaya et al., 1988).

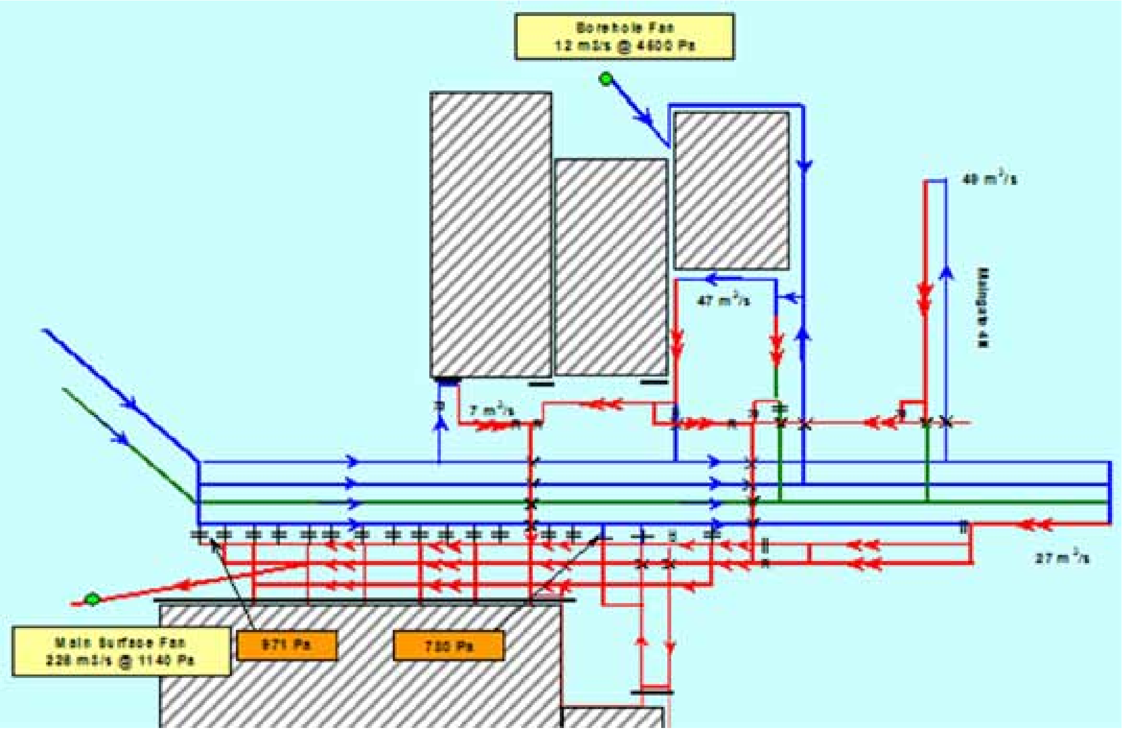
Regulation for the last 90 years

Early 1900s. Discussions concerning the safety of booster fans in underground coal mines resulted in initial regulations in the 1920s and were influenced by several accidents, fires and explosions related to their use. Research was performed to study booster and auxiliary fans for the purpose of formulating recommendations (Horsley, 1926; Smith, 1927). In December 1928, the Mine Safety Board recommended that auxiliary fans or blowers should not be used in coal mines as a substitute for methods of regular and continuous coursing of the air to every face (Mine Safety Board, 1928).

In 1937, booster fans were addressed directly for the first time (Mine Safety Board, 1937). Their use was suggested only where it is not practical to put down a new shaft and when the air pressure required would be so high as to prevent proper operation of underground ventilating doors. The reason for this recommendation was that re-

Figure 1

Ventilation system of the North Goonyella Mine prior to booster fan installation (Marlborough, 2003).



circulation of mine air was found in most investigated installations.

The use of booster fans was regulated a year later (*Federal Register*, 1938).

These regulations stated, in part, that "Booster and auxiliary fans may be used underground only with the written permission of the district mining supervisor under specified conditions. With a booster fan, these conditions include protection against fire, and automatic starting and timing device to prevent a fan from starting after it has been stopped long enough to permit an accumulation of gas, and a recording device to show continuity of fan operation. Also, a booster fan shall not be operated where more than 10% of the air is recirculated by the fan."

These guidelines were added to several state laws. In some coal mining states, utilization of booster fans was further restricted by additional safety requirements.

Late 1900s and early 2000s. The Federal Coal Mine Health and Safety Act of 1969 (Coal Act) did not specifically prohibit the use of booster fans in underground coal mines. The requirement of main fans on the surface, however, acted effectively against the use of booster fans underground (Ramani, 1993).

In 1989, when the U.S. Mine Safety and Health Administration (MSHA) published a new proposal for coal mine ventilation rules, it provided an opportunity for revising and updating the ventilation regulations issued almost two decades prior, although the final rule in 1992 still does not permit the use of booster fans in underground bituminous and lignite coal mines. Reasons cited by MSHA include existing approval criteria, established industry practice and several safety concerns associated with such issues as recirculation, fires, fan control, noise and dust. About coal mine fans, section 30 CFR § 75.302 states: "Each coal mine shall be ventilated by one or more main mine fans. Booster fans shall not be installed underground to assist main mine fans except in anthracite mines."

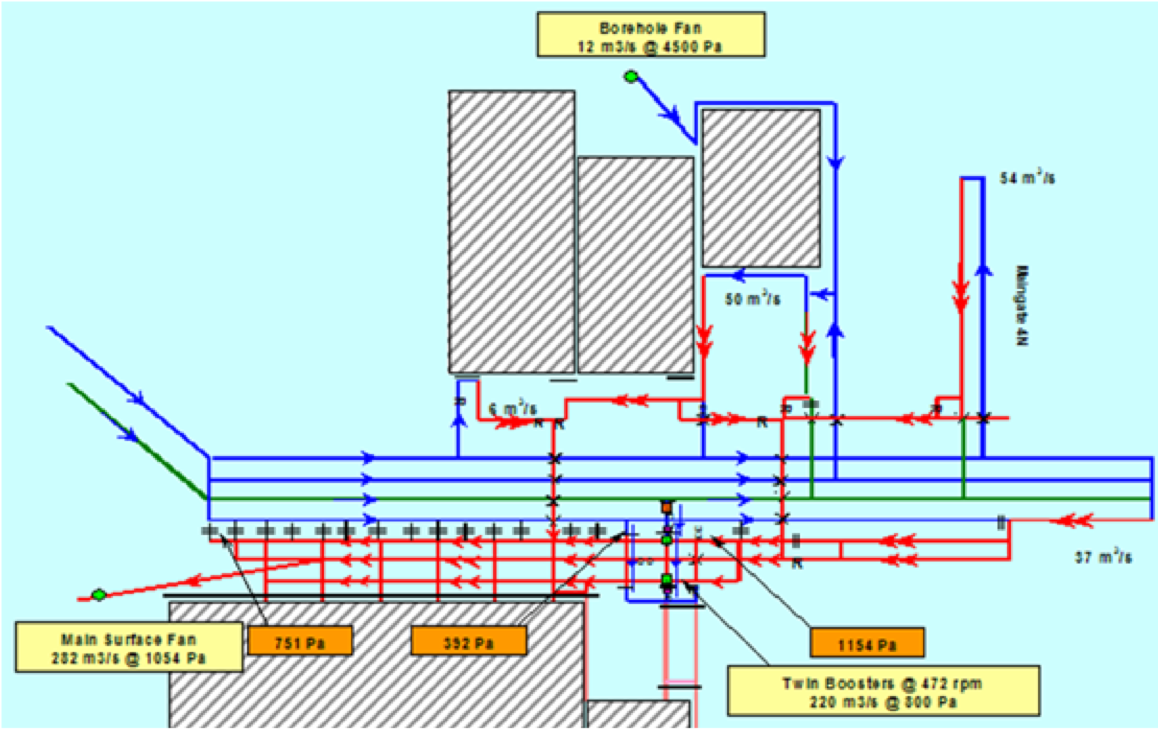
Several members of academia presented their opinions in the late 1980s and early 1990s. Hartman (1987) said: "Why are gassy mines restricted from using booster fans? The rationale is that main fans cannot be safely operated and adequately controlled when located underground in flammable atmospheres. While such a claim might have been valid 40 years ago, it has no bearing today, and within 15 years, will be totally discounted. I predict that booster fans in U.S. coal mines will be legalized in the near future. Arguments in their favor are compelling. Further, no new technology is needed — computerized, remote, automated control systems of high reliability are now available and in operation in other countries. The exclusion of main fans underground compels ventilation engineers to overregulate mines in an effort to balance disparate ventilation circuits — resulting in excessive energy waste, air leakage, insufficient air delivery to some working faces and generally less efficient and effective air distribution throughout our mines."

McPherson (1991) continued: "At the present time, attempts to install booster fans in U.S. coal mines are effectively blocked by MSHA and proposals have been promulgated to render booster fans illegal. If this prohibition becomes law, then our underground coal mining industry would be denied a powerful and efficient means of improving the health and safety of mine workers — a means that has long been employed successfully in other coal mining countries. Where incidents have occurred historically, they have arisen from misuse or mismanagement of equipment."

Ramani (1993) concluded: "The restriction on booster fan use reduces flexibility in mine system design and op-

Figure 2

Ventilation system of the North Goonyella Mine after booster fan installation (Marlborough, 2003).



eration. As depths to coal seams increase, as panels become larger and wider and as rates of productivity inch higher, the difficulty of designing coal mine ventilation systems with fans located only on the surface must surely increase. Without approval of booster fans in underground mines on an experimental basis, data and experience in U.S. coal mines will not be developed."

Legislation in countries permitting the use of booster fans in underground coal mines. In the United Kingdom, where booster fans are commonly used in underground coal mines, the law requires booster fan installations to be examined every 30 minutes and to have basic monitoring information recorded every two hours. The Office of Health and Safety Executive (HSE) can issue exemptions from the requirements and, in return, it may impose conditions (Leeming, 2008).

In South Africa, the regulation concerning main fans applies also to booster fans. Monitoring and early warning of defective operation are required. Every booster fan has to be examined for effective operation at intervals not exceeding three months. Power supply has to be provided from two different sources. Booster fans have to be installed, operated and maintained in accordance with a written procedure prepared and implemented for that purpose (van Zyl, 2008).

In Australia, the states have independent mine safety regulations. The large underground coal operations with possible interest in booster fans are located mainly in Queensland and New South Wales. In Queensland (Queensland Consolidated Regulations, 2001), at least one methane monitor must be located near the fan to warn workers if concentrations exceed 1.25% and to shut the fan down if concentrations exceed 2.0%. Standard procedures for each fan include procedures to be followed when the fan activates an alarm. In addition to monitoring the fan's static pressure, mine operators must be sure to continuously monitor other fan operating conditions. Only specifically designated persons are permitted to start, stop or alter the fan. As an example, the ventilation system of the North Goonyella coal mine is presented in Figs. 1 and 2 (before and after booster fan installation).

The legislation of New South Wales (New South Wales government, 2006) states that the operator of an underground mine must ensure that any auxiliary ventilation fan used in the underground parts of a mine is located and operated in such a manner as to prevent recirculation of air through the fan. Also, installation of a booster fan is considered a high-risk activity and requires a three-month waiting period prior to use. Information that is required to be submitted includes the fan location and a ventilation plan that summarizes the risks and controls to be put into place to operate the fan.

Federal regulations in Canada are no longer in effect. Instead, individual Canadian provinces have regulations concerning booster fans. Current and potential underground coal mining operations are located in British Columbia, Alberta and Nova Scotia (Bonnell, 2008).

In British Columbia, a pressure quantity survey is required to determine the necessity for a booster fan, the expected performance range, an adequate location and the fan's effect on the rest of the ventilation survey. Also, an employer must ensure that a booster fan is located in such a manner that, if it stops, the free passage of ventilating air to or from a main fan will be restricted as little as reasonably practicable. These requirements are stated also in Nova Scotia's regulations (Nova Scotia Regulations, 2009). In addition to these regulations, booster fan controls have to be protected and sufficiently remote from the fan locations. Main fan, booster fan and associated equipment have to be inspected at least once a week. Main and booster fans with a capacity of 37 kW (50 hp) or more have to be inspected for overheating of bearings or fan failure at least every 30 minutes if the fans are not continuously monitored for these issues and at least every eight hours if they are continuously monitored. The competent person who inspects the fans and equipment must prepare a report of the inspection.

It is required by Alberta regulations that the free passage of air delivered by a main fan is not restricted if the booster fan stops. If the main fan stops, the booster fan must also stop.

The International Labour Office (ILO, 2009) presents several recommendations concerning the safe use of booster fans in underground coal mines:

- Fans must be installed and operated without detriment to the safety and health of employees.
- A ventilation survey by a qualified person is required prior to installation.
- The fan must conform to standards for inspection, monitoring, maintenance and use.
- The fan should be equipped with safety and operational efficiency monitoring devices with alerts for reduced ventilation, air reversal, dangerous gases, fires or electrical disruptions.
- Fans must be approved by a competent authority.

In addition to these guidelines, it is suggested that the manager of the mine formulate booster fan rules, add them to the ventilation plan and post them at a conspicuous place at the mine. This step is recommended where national laws, regulations and standards do not provide, or provide ineffective or outdated, guidance on ventilation.

Advantages and disadvantages of booster fans

Advantages of booster fans. There are several ways of gaining advantage from the use of a booster fan. Even if booster fans are not suitable for every situation, they are capable of providing improvements in various underground environments when properly sized and located (Calizaya et al., 1988; Calizaya et al., 1990; McPherson, 2009). Booster fans can be used to:

- Improve the airflow distribution in the mine, especially in difficult-to-ventilate areas.
- Increase flow rates in high-resistance circuits.
- Provide air to areas with difficult surface conditions (such as mining sections under water).
- Reduce air pressure differentials between intake and return airways.
- Reduce leakage between intake and return airways.
- Reduce overall power costs.
- Reduce development costs.
- Decrease main fan pressure requirements.
- During mine fires, prevent smoke from entering intake airways.

As an underground coal mine becomes older or larger, a significant portion of the fresh air is short-circuited through leakage paths. In large mines, high pressure differentials required to move air to faces can result in considerable air flow losses through stoppings. However, air leakage in a mine can be controlled by the addition of pressure sources in the form of underground booster fans (Moll and Lowndes, 1994).

There are several ways to enhance the safety of booster fans. They can be equipped with electrical interlocks wired directly to the surface fan power circuit to avoid inadvertent recirculation caused by the stoppage of main surface fans while the underground fans are still operating. Modern monitoring systems can be used to collect data and to exercise booster fan control. The parameters monitored at or near a booster fan may include methane, carbon monoxide, air velocity and pressure, fan speed, vibration, motor and impeller bearing temperatures and electric power (Calizaya et al., 1990). It is also possible to separate the fan and the motor from each other to reduce fire and explosion risks.

The usual guidelines followed in the mines to avert incidents associated with booster fans are based on Kumar and Sastry (1997):

- An effective mine communication system.
- Well-planned emergency/ evacuation plans.
- Continuous monitoring of mine environment.
- Use of fireproof materials with the booster fans.
- Simulation studies to assess the effects of stoppage of fans in the mine and/or closure of airways due to roof falls.
- Proper selection and location of booster fans.

Disadvantages of booster fans. Section 75.302 of the 1992 regulations requires all main mine fans to be installed on the surface. According to an MSHA proposed decision and order (PDO) regarding a petition to allow the use of a booster fan in an underground bituminous coal mine, this regulation serves to protect main mine fans from fires and damage, so that in the event of an underground explosion ventilation can be maintained (Langton, 2003). Several other safety concerns are also listed in the mine-specific PDO regarding the proposed use of a booster fan:

- Booster fans reduce the ability to control recirculation of air underground.
- If an underground main mine fan is damaged, booster fans limit opportunities to restore ventilation to specific areas.
- If it is necessary to remove electricity from an area, ventilation can be interrupted.
- A fire or explosion can make it impossible to control the booster fan in order to adjust ventilation in specific areas of the mine.
- Booster fans can also increase noise, respirable dust and float coal mine dust levels.

Other possible disadvantages, described by Calizaya et al. (1990) and Brake and Nixon (2006) include:

- Problems in case of main fan/booster fan stoppage.
- Complexity of the ventilation system and its management.
- Inappropriate use of a booster fan that may result in increased operating costs and/or increased leakage.

Unplanned, uncontrolled recirculation is the most prominent potential drawback of booster fan utilization. When booster fans are not designed, installed, located or operated correctly, the possibility of uncontrolled recirculation exists. If the supply of fresh air is not maintained at a minimum level, then uncontrolled recirculation may cause an increase of contaminant concentrations to unacceptable levels.

Another issue often mentioned is the question: What happens if the booster fan/main fan stops? The effect of these stoppages should be studied and taken into account in planning. Minimum required airflows have to be maintained at all times. The consequences of either the main fan or the booster fan going into stall should also be studied during the initial design of a booster fan setup. Regulation concerning booster fans in M/NM mines in the U.S. requires interlocking, so stalling does not present a problem. A similar requirement for booster fans could be implemented in coal mines.

The overall capital costs of a combined surface-booster fan system may be greater than that of a larger surface fan alternative, due to the need for additional underground excavation and a monitoring system. Also, a badly positioned booster fan can exacerbate leakage problems.

Research in the US

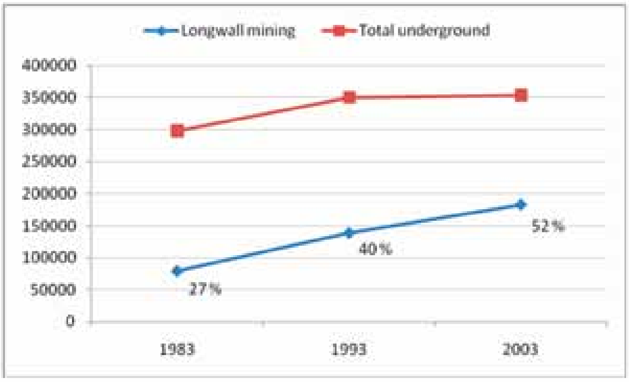
Research programs. Virginia Polytechnic Institute and State University studied the optimization of multiple fan systems that included booster fans. A critical path-crashing technique to optimize multiple fan ventilation systems with booster fans was introduced first (Bhamidipati and Topuz, 1983). Further research by Wu and Topuz (1987, 1989) describes other techniques, like linear programming, the out-of-kilter method and the network simplex method. Based on these studies, the optimal methodology is developed and examples presented by Wu et al. (1991). The authors reported that computer software based on the methodology would be developed, but no further studies were forthcoming. This may be due to the change in regulations that occurred in 1992.

The largest single effort to study booster fans in the U.S. was performed as a contract under a grant from the U.S. Bureau of Mines in 1985. The research started with an extensive survey on the use of booster fans. The study showed that 318 booster fan installations were located in underground coal mines worldwide, with the United Kingdom being the major user, followed by South Africa and Canada (McPherson et al., 1985). Also, a study concerning the attitudes toward the use of booster fans in the coal mining industry of the U.S. was conducted. It was found that out of the represented coal mines, 42% were interested in installing booster fans. Out of the uninterested operations, 52% considered the risk of recirculation to be the primary reason for not taking an interest in using booster fans and only 6% pointed out other primary reasons (McPherson et al., 1985).

The study was expanded in the late 1980s to include booster fans and regulators at fixed locations and to minimize the overall power consumption. The problem was studied by Calizaya et al. (1987) using the commercially available ventilation simulator VNETPC. A computer program called MFSELECT was developed to determine the fans and regulators that would fulfill the airflow requirements of a mine and minimize the total power consumption. The application of the program was illustrated by a detailed solution of a sample problem based on the Jim Walter Resources' No. 7 Mine. This solution described the basic requirements for the design and operation of booster fans and showed their potential benefits (Calizaya et al., 1987; Calizaya et al., 1988; Calizaya and Mousset-Jones, 1989; Calizaya et al., 1990).

Figure 3

Longwall mine production in the U.S. in years 1983, 1993 and 2003 (1000 short tons).



Effect of longwall mining on booster fan research. What suddenly initiated this research in the 1980s after so many quiet decades? It can be speculated that the resurgence resulted from increasing longwall productivity in the U.S. in the 1980s and the increasing airflow requirements needed to control the resultant dusts and gases. The limited number of airways in longwall mining requires high ventilation pressures to overcome the resistance.

Nationally, longwall mines produced 126 Mt (139 million st) of coal in 1993, or 75% more than in 1983. In contrast, total underground coal production increased by only 17% throughout the same period. By 1993, longwall mines accounted for 40% of underground coal production (Fig. 3), up from 27% in 1983 (Energy Information Administration, 1995). In 2003, already more than half of the total underground coal production occurred in longwall mines (National Mining Association, 2008).

Petitions from industry

Petition process. Under section 101 of the Federal Mine Safety and Health Act of 1977, a mine operator may petition and the Secretary of Labor may modify the application of a mandatory safety standard, such as § 75.302, to a mine if the secretary determines that:

1. An alternative method exists that will guarantee no less protection for the miners affected than that provided by the standard; or
2. that the application of the standard will result in a diminution of safety to the affected miners.

MSHA bases the final decision on the petitioner's statements, any comments and information submitted by interested persons and a field investigation of the conditions at the mine. In some instances, MSHA may approve a petition for modification on the condition that the mine operator complies with other requirements noted in the decision.

To date, there have been two petitions filed by mine operators to use booster fans in underground bituminous mines. In both cases, MSHA determined the proposals did not provide at least the same level of protection as the standard.

No. 7 Mine, AL. In 1985, Jim Walter Resources Inc. (JWR) noticed that additional ventilation capacity was required to mine a remote block of its No. 7 Mine in Alabama. Its personnel studied the situation and the review process indicated that either a 7-m (23-ft) intake airshaft or a 746-kW (1,000-hp) underground booster fan installed in the east main intake would satisfy the predicted airflow requirement.

A petition for modification to operate an underground booster fan was submitted to MSHA on June 11, 1986. It included safety features, such as electrical interlocking, independent power supply and remote atmospheric monitoring and was based on references obtained from the UK and Australia. The potential for recirculation of air through the fan was given as a primary reason for denial of the plan after evaluation by MSHA.

JWR developed an improved plan. Various booster fan locations were simulated in search of a more suitable fan site. This defined a new location, in which a fan equipped with a 298-kW (400-hp) motor would fulfill the ventilation requirements. The simulations indicated that under normal operating conditions the pressure differentials would be from intake to return at all locations, so recirculation conditions would not exist. Events of booster fan failure and shutdown were also simulated with favorable results. The new plan was proposed to MSHA on June 2, 1987. Safety considerations, like fireproof housing of the motor, transformer and starter, and a fire-sensing system with dry powder extinguishers, were included in the plan. Also, the booster fan would have been attached to a separate power circuit from the surface through a borehole. It was also noted that the booster fan would be located in a main return, away from the working face and, thus, dust and noise were not considered to be a problem (Sartain and Stevenson, 1988).

The new plan was inspected by MSHA. Ventilation engineers from the MSHA Technical Support Center performed a detailed ventilation survey of the mine in November 1988. However, the plan failed to convince MSHA and the booster fan petition was later denied again (McNider, 2008).

Loveridge No. 22 Mine, WV. On Sept. 15, 2003, Consolidation Coal Co. filed a petition for modification of 30 CFR 75.302 at the Loveridge No. 22 Mine in West Virginia. The petition described an alternate method that would allow use of an auxiliary fan to prevent the freezing of the slope during the winter months. Safety considerations in the petition included fireproof housing, an automatic fire suppression system, CO, temperature and vibration monitors and daily inspection.

MSHA pointed out after the investigation that the auxiliary slope fan would be used to improve or augment ventilation in a segment of the mine. Consequently, the auxiliary slope fan was in reality a booster fan. Simulations demonstrated that major ventilation changes occurred when the auxiliary slope fan stopped. Slope ventilation reversed and the intake at one of the shafts decreased by 53,000 cfm.

In addition, MSHA determined several safety issues that were not addressed by the plan, such as vulnerability to damage from a major mine fire, lack of an independent power circuit and no means to start or stop the fan remotely from the surface. Also, MSHA pointed out a mine fire accident that had happened in early 2003, in which a similar fan installation had hampered firefighting efforts. For the reasons described above, MSHA concluded that the alternative method would not at all times guarantee no less than the same measure of protection afforded the miners under 30 CFR 75.302, so the petition was denied (Langton, 2003).

Conclusions

It can be seen that the interest in booster fan use in underground coal mines of the U.S. has fluctuated during the last 90 years. Booster fan research essentially stopped in 1992, following the final coal mine ventilation rule that outlawed booster fans. The booster fan issue was reopened in the search for alternatives to belt air during the Technical Study Panel meetings in 2007 (Anon, 2007). Use of booster fans was presented as one of the three recommended research topics in the *Final Report of the Technical Study Panel on Utilization of Belt Air and the Composition and Fire Retardant Properties of Belt Materials in Underground Coal Mining* (Mutmansky et al., 2007). The MSHA response to the report (*Federal Register*, 2008), released in June 2008, did not address the research recommendations. However, in the text MSHA noted the need to maintain the pressure differential from the primary escapeway to the belt air course to prevent the leakage of contaminants to the escapeway in the event of a fire. This pressure differential could theoretically be achieved by using a booster fan.

Since the passage of the regulation in 1992, several safety improvements have become available. Use of separate power circuits, AMS improvements and wireless communication technology can make a difference in the safety of booster fan use. Also, the research, experiences and regulations of other countries can present important comparisons for the potential application of booster fan use in the U.S.

However, under current regulations, booster fan research in the U.S. will be challenging, due to nonexistent options for field studies in coal mines. Computer simulations, laboratory studies and comparisons to M/NM mine practices are expected to be the main research tools to evaluate booster fans' possible safety advantages. These studies will include ventilation network simulations of underground operations to evaluate their ability to assist in defining the safest and most feasible locations for booster fans. Safety concerns will be addressed by comparing and evaluating current practices and fan monitoring systems. Finally, the impacts of existing domestic and international booster fan safety regulations will be reviewed for relevance to U.S. mining conditions.

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Disclosure

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