

# Improvement in Booster Fan Applications for US Coal and Metal/non-Metal Mines through the Application of Technology, International Operating Experience, and NIOSH Research

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Booster fans have been effectively used in underground gassy and non-gassy, metal, non-metal, and international coal mines for increasing airflow to difficult-to-ventilate areas. Health and safety aspects of booster fans were evaluated based on the previous body of domestic and international research, which showed that except for US-based non-anthracite coal mines, booster fans are perceived as a safe option to achieve increased ventilation capacity that results in health, safety, and environmental benefits.

Inherently, booster fans themselves are not a hazard; it is their installation and operation that are of concern. This analysis showed that when located, sized, and operated correctly, booster fans are a tool to be considered to safely increase mine airflow. Improved technology in ventilation network modeling, atmospheric monitoring, and control of ventilation systems can reduce the risk associated with underground mine booster fan applications. Based on this body of knowledge and recent National Institute for Occupational Safety and Health (NIOSH) research, a compilation of effective booster fan installation and operation recommendations is presented that can be incorporated to improve the use of booster fans in underground coal and metal/non-metal (M/NM) mining applications.

Keywords: Mine Ventilation, Underground Mining, Booster Fans, Recirculation, Coal Mining, Metal Non-metal Mining

## 1. Introduction

There are two frequently cited examples of booster fan failure in mines. The first is the Sunshine Mine Fire in 1972 where a bulkhead fire caused a short circuit in the ventilation system, recirculating fire contaminants [1,2]. The second is the 1959 Auchengeich Colliery fire in Scotland where the booster fan drive belt caught fire, spreading to roadway timber [3,4]. The former led to passage of the 1977 Federal Mine Safety and Health Act and the second resulted in a major redesign of underground fan installations, both milestones in mine safety regulation.

Regulatory concerns related to booster fan operation are the recirculation of methane (in coal mines) and fire contaminants, monitoring and control issues, increased potential for spontaneous combustion, and leakage around the booster installation. Despite these concerns, booster fans have been successfully operated in US and international M/NM mines, including gassy mines, as well as in selective international coal mines. Also, controlled recirculation has been successfully implemented in international coal mines. Years of operating experience have shown that booster fans have safely provided additional mine airflow to improve miner health and safety in both gassy and non-gassy coal and metal/non-metal

mines, with and without the use of recirculation.

### 1.1 Booster Fan Use and Issues – M/NM mines

Booster fan use has a successful recent history in underground mining, such as at the Homestake Mine [5], Ruttan Mine [6], FMC Trona Mine [7] and Barrick Meikle Rodeo Mine [8], encompassing metal, non-metal, multi-level, and single-level applications. The Homestake mine recirculated return air through an underground cooling facility to improve the deep mine's working environment, the Canadian Ruttan Mine recirculated at the mine level to save heating costs, the FMC booster allowed safe and effective ventilation of a gassy metal/non-metal longwall retreat mining block at the far extent of the mine's workings, and the Meikle-Rodeo mine assured ventilation of a complex multi-deposit underground operation. Booster fan applications add ventilation pressure, assisting main fans in distributing airflow to areas not effectively ventilated by main fans.

Health and safety issues relevant to operating a M/NM booster fan system are: allowance for changes in the existing ventilation system, such as main fan maintenance [9]; recirculation of dust and gasses [10,11]; and minimized recirculation of mining-generated and fire

contaminants [5]. An extreme example of a related health and safety issue is the Sunshine Mine fire [1], which resulted in the death of 91 miners—although this example is not of a booster fan failure, but one of ventilation system component failure exacerbated by booster fan operation.

## **1.2 Experience and Research with Booster Fans in Coal and Gassy M/NM Mining**

Coal mine booster fans have been primarily utilized overseas (South Africa [12]; United Kingdom [13]; Australia [14,15] and have been effectively summarized by Martikainen and Taylor [16]. Use of boosters in US coal mines has been prohibited in §75.302 [17] but has been recommended as a potential option to increase airflow by Ramani [18], McPherson [19], Moraru et al. [20], and others [16, 21].

Meyer's experience with a South African coal mine booster fan utilized in a district recirculation system for partial air re-use concluded:

*To date, the continuous gas monitoring systems have not recorded any increase of the gases found in the underground workings as a result of the recirculation of the air.*

*It can therefore be concluded that the recirculation project showed the use of recirculated air in a ventilation district, to increase airflow to problem areas, to be a feasible and economical short term solution, as opposed to the use of additional ventilation shafts.*

The Mine and Health Safety Administration (MSHA) allows booster fan installations in gassy Class III metal/non-metal mines per 30CFR §57.22207 [17] which also emit methane and utilize similar mining methods and equipment as coal mines. Noted previously, a gassy trona mine has safely and effectively operated a booster fan in a longwall retreat section utilizing room and pillar development while emitting over 3 million cubic feet of methane per day. Most methane from this mine is emitted in the active longwall face and gob area [22]. The booster fan installation was utilized in a difficult-to-ventilate area distant from intake and return shafts. Larger methane inflows and outby leakage required additional airflow to keep methane levels below statutory limits. Once mining retreated closer to shaft areas, the booster fan was placed on standby and ultimately removed from service.

Booster fans have also been effectively used internationally in the United Kingdom, South Africa, China, and Australian coal mines [14, 15,23] . Motivation to re-examine US booster fan use came about as one of three priority research areas cited by the Technical Study Panel (TSP) meetings[24], which recommended investigation of coal mine booster fan use as a means to improve airflow to mining areas, thus minimizing fire and explosion risks. MSHA's later response to the TSP final report [25] did not address TSP recommendations

regarding booster fans [26]. MSHA's approach to potential use of booster fans continues to focus on managing recirculation, leakage, poor mine design, float and coal dust, recirculation of smoke, and utilizing other alternatives [27]. These are reasonable concerns that have been examined in the international mining community, and have been successfully addressed.

Many coal mines have allowed recirculation of return air [23,28] with success, giving confidence that the booster fan use and recirculation issue may be managed and resolved safely. Because increased airflow to improve safety by more effective dilution of contaminants is the goal, booster fan installations often have the potential to more quickly provide increased airflow and increased velocity to a ventilation-challenged mine than other options such as additional shafts or upgraded surface fan facilities.

## **2. Atmospheric monitoring and control technology and booster fans**

M/NM mines have been safely utilizing booster fans for decades and their use is an accepted industry practice. A recent development is the concept of Ventilation on Demand (VOD) [29], which involves incorporating control of ventilation systems through monitoring airflow control devices such as fans, sensors, and regulators in conjunction with the variable airflow demands related to variable mining equipment use, blasting, and personnel. The thrust of the VOD system is two-fold: to direct air to where it is actively needed during changing mine operations and to drive operational cost savings from reduced airflow when possible. From a safety standpoint, the additional air is welcomed as the standard ventilation system is often slow to react or does not respond to changes in production requirements. Through the use of contaminant and ventilation control monitoring, additional information is provided to mine management and operations to better control all facets of the ventilation system. When incorporated with the total ventilation system, this marriage of monitoring and control technology through development of VOD systems may improve airflow within the changing mine environment, benefitting not only the day-to-day working conditions, but response to emergency situations, such as excessive contaminant levels or a mine fire.

Advances in monitoring and control ventilation technology has been more prevalent in M/NM mines, but may be further implemented in coal mines to achieve greater knowledge of the state of contaminants and mine airflow for the benefit of management and miners. With this knowledge, management can make better decisions regarding production planning, airflow distribution, and emergency response, and allow miners to better know the present state of their work areas. The use of atmospheric monitoring systems (AMS) technology in coal mines has

been locally applied in belt monitoring systems for CO and smoke to allow use of belt air as additional intake capacity [26]. Ultimately, the successful application of belt air at many mines, which mines accomplish through MSHA's Petition for Modification process, has resulted in MSHA amending existing underground mine safety standards to incorporate this successful method [30]. Additionally, since the 1980s mine network modeling programs have improved from simple network programs on mainframe computers to those capable of modeling natural ventilation, contaminants, and mine fires, which can be displayed with exceptional graphics on an engineer's desktop. Recent technology has combined real time in-mine contaminant and airflow quantity monitoring from an AMS system with the Ventsim network model [31], which allows for three-dimensional modeling based on ventilation data.

Booster fans have had a long history of successful operation in various international coal mines. Concerns about recirculation, methane, and fires have been effectively addressed to the satisfaction of the mines and inspectorate. Successful methods were outlined in Gillies and Calizaya [23]. There are serious challenges in all underground booster fan installations but as experience has shown, with effective engineering, management, training, and inspection, they can and have been overcome. In the extreme case of booster fan-induced recirculation, safe operation is noted by Meyer [12], Marks [5], and Robinson[28] with the major concern of methane recirculation being managed. Effective use of contaminant, fan, and pressure differential monitoring in conjunction with variable frequency drives (VFD) allows close control of differential pressures and changing mine conditions to minimize recirculation. Favorable experience has been documented in applying VOD technology to actively

control main, booster, and auxiliary fans in Canadian [29] and US metal mines [8], and can be further applied to coal mine booster fan systems. AMS monitoring has improved and developed dramatically in conjunction with VOD systems in the past few years.

### 3. NIOSH booster fan research in coal and M/NM mines

NIOSH has been involved with booster fan and recirculation research since the late 1980s, beginning with examining health and safety issues involved with increasing airflow in M/NM gassy trona mines [10, 23-34]. These tests involved utilizing auxiliary and booster fans in continuous miner sections (Figure 1) and mining districts (Figure 2) to improve airflow to the mining face. This work showed that contaminant levels did not increase, total dust rapidly settled in return airways, and respirable dust levels remained fairly constant in section recirculation scenarios but greatly decreased in mining district applications. This reduction was due to dilution from idle mining sections, leakage, and the addition of relatively uncontaminated air from shops and sumps. Dust reduction methods utilizing water sprays at the face in exhaust tubing and in return airways showed limited success. It was also noted that increased district airflow from recirculation booster fans reduced total mine intake airflow, slightly lowering the dilution effect. Researchers noted that recirculated contaminants could be effectively managed by diligent monitoring and control in conjunction with good planning.

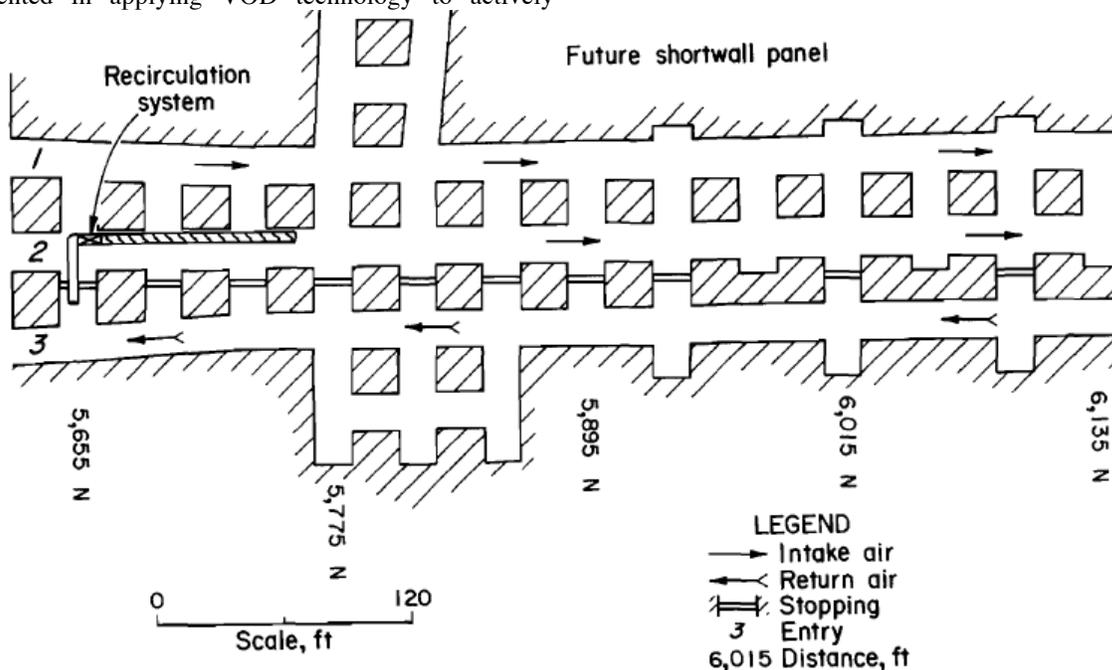


Fig 1. Three-entry auxiliary fan induced section recirculation test layout.

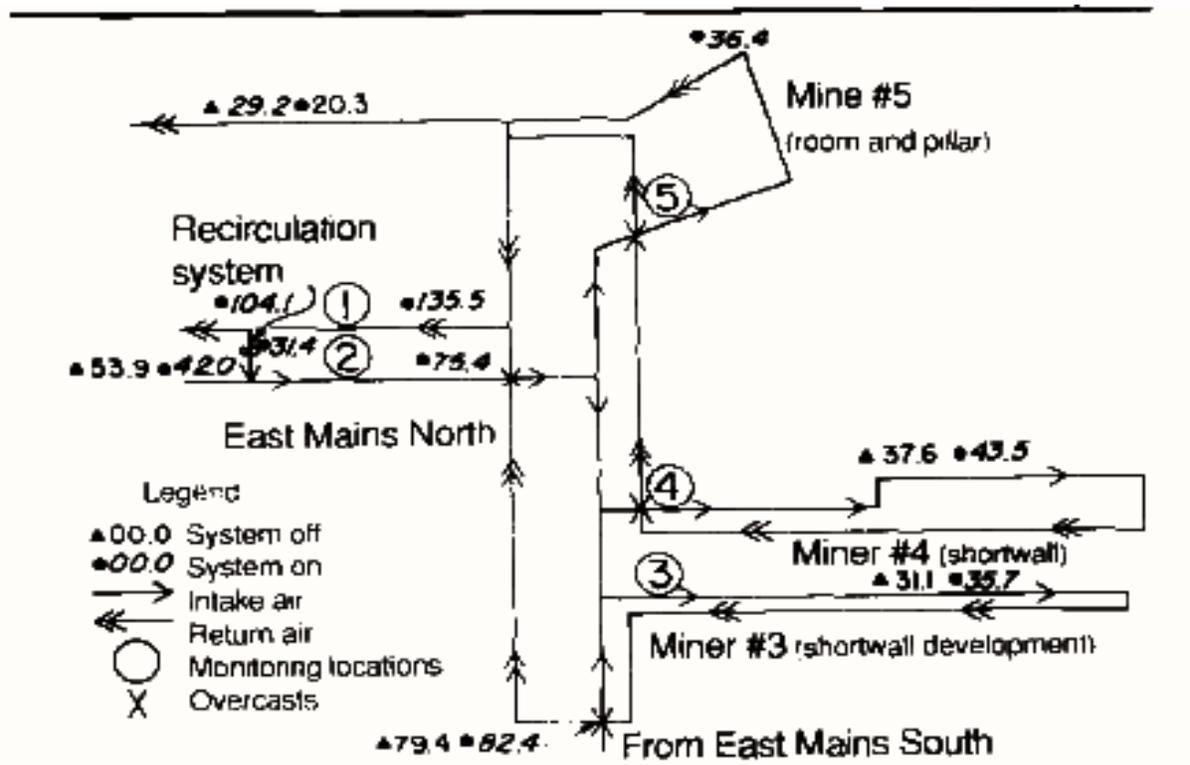


Fig 2. District recirculation system layout, with recirculation/booster fan (arrow) located between monitoring location 1 & 2.

More recently, field research was conducted in the Bruceton Safety Research Coal Mine and at a large trona mine (Figure 3 and 4) in combination with network modeling [21]. This work was driven by a recommendation from the Belt Air Study Panel [24] and geared towards examining booster fan use in a room-and-pillar environment on a small and large scale, to determine its effect on the overall ventilation system. Research concluded that booster fans can be an effective tool to increase airflow in underground

coal and M/NM mines. The combination of both large and small mine field tests with network modeling showed: booster fans can be used to increase face airflow; outby booster fan locations can minimize recirculation; moderate booster fan pressure-induced localized recirculation would result in undetectable amounts of recirculated methane in intake air; and multiple booster fans can be used to manage leakage and recirculation.

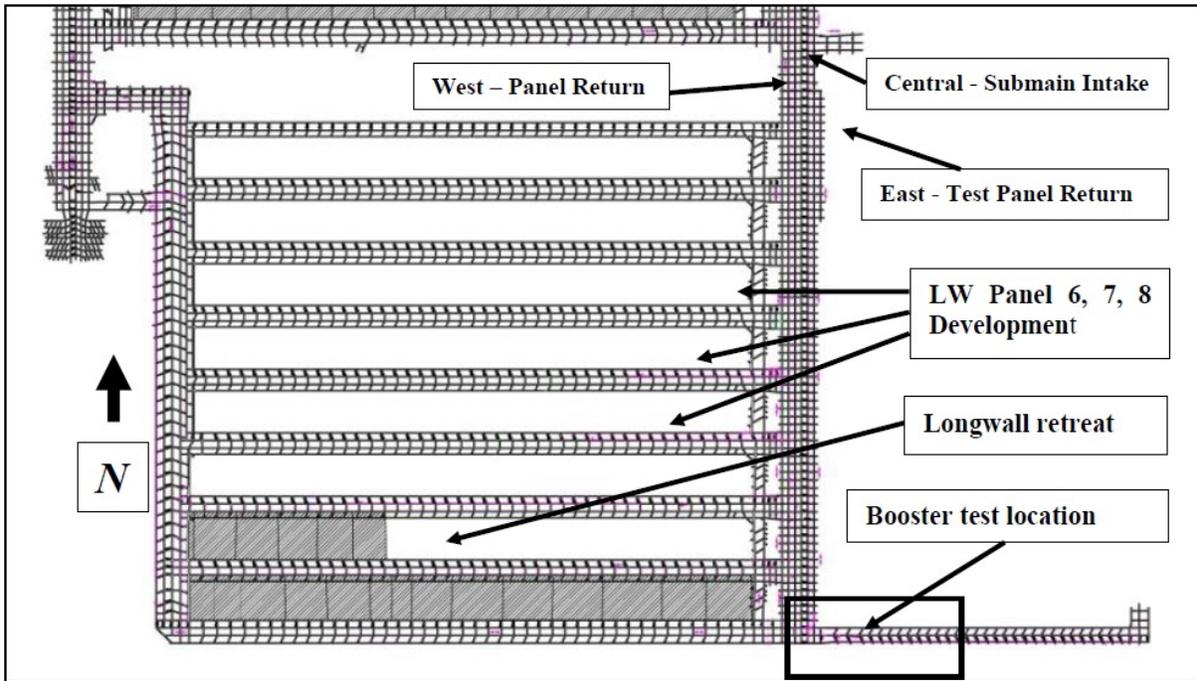


Fig 3. Booster fan test location in relation to mining areas in a large room and pillar mine.

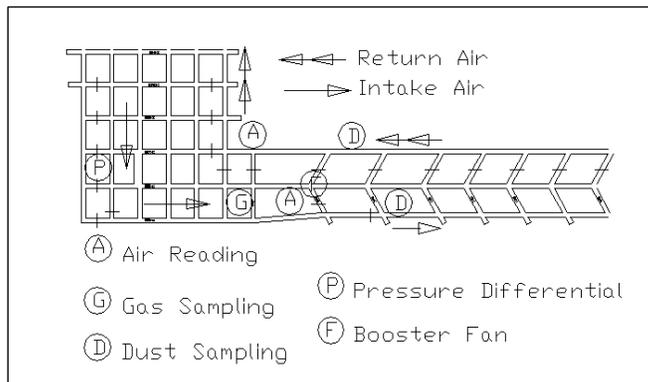


Fig 4. In-line intake booster fan test location detail from Figure 3.

A comparison of field vs. network modeling (Typical Ventgraph network model shown in Figure 5) results showed that leakage of stoppings did not behave identically when pressures across them changed from an intake/return direction to return/intake due to booster fan over-pressure. As such, resistance models needed to be modified; and to ensure that leakage volumes did not significantly change, stoppings near a booster fan needed to be sealed on both sides and be constructed in a substantial manner. In coal mines, safety is enhanced by pressurizing the intake entry, which minimizes the

potential influx of methane from the return. Using moderate booster fan pressures less than 125 Pa/0.5 in wg will minimize recirculation, making detection of methane in intake air unlikely with normal mine gas monitors because of concentrations less than 0.1%. Multiple booster fan installations contribute to safety and efficiency, but ultimately complicate the ventilation system. Any booster fan system requires considerable vigilance in a constantly changing mine ventilation environment, and should be well designed initially with network models kept up to date.

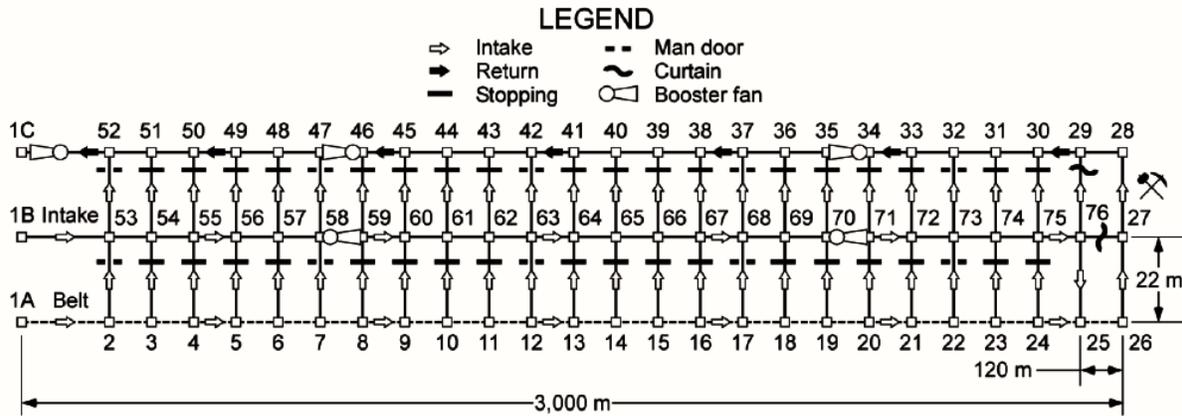


Fig 5. Extended development model with four booster fans utilizing Ventgraph.

Further NIOSH field work focused on booster fan applications in M/NM two mines: a multi-level room-and-pillar mine and the second a multi-level multi-deposit hardrock mine. The first project [35] investigated utilizing a booster fan in a controlled recirculation setting (Figure 6) to improve airflow to a multi-level room-and-pillar operation with limited options to increase airflow. The intent was to evaluate a ventilation system for potential use of recirculated air by determining existing air quality, site selection, modeling, and implementation. Ultimate implementation was not possible due to the mine being classified as gassy by MSHA, but offered a good proving ground for the evaluation concept for other mines interested in utilizing district recirculation. Data showed this mine was a good candidate for booster fan-induced controlled district recirculation by virtue of low return air contaminant concentrations, resulting from considerable idle panel dilution and settling of dust in return airways. Key

findings for booster fan installation were that return air quality was actually better than intake due to dust settling, leakage and dilution, except in the presence of very low methane levels that would be undetectable in intake air at proposed recirculation levels, as noted in previous NIOSH modeling and field research. However, due to long return air system travel times, any mine fire would take many hours to reach the booster fan site, and encounter considerable dilution by other merging return air splits. Findings showed that booster fan-induced controlled district recirculation in conjunction with monitoring and control technology may result in improving air quality and quantity in underground workings. It is important to remember that the use of recirculation to increase local circuit airflow will moderately reduce total mine intake fresh air airflow due to the main fan response to increased inby circuit airflow.

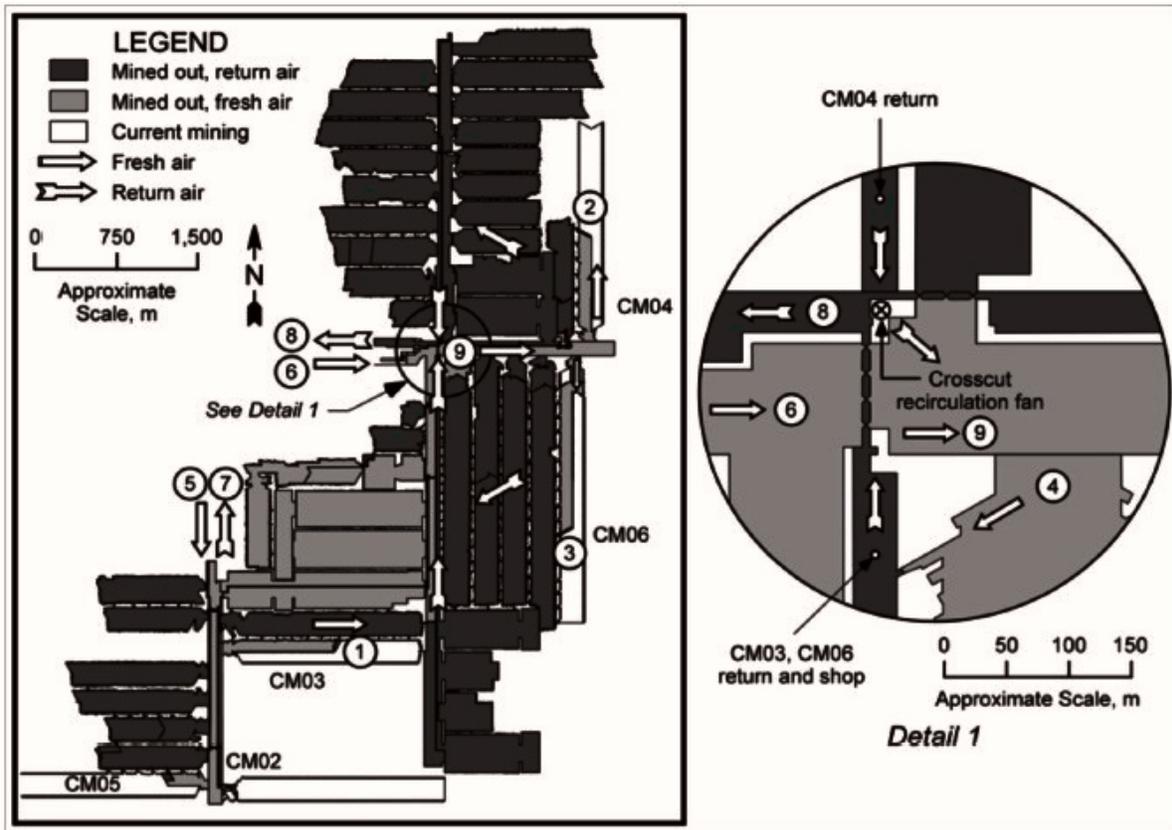


Fig 6. Plan view of upper mine level, with detail 1 showing the recirculation area crosscut recirculation fan connecting intake and return through a stopping bulkhead. Circled areas are mining locations or underground facilities.

Another project [9] involved induced recirculation by underground booster fans during main fan maintenance, in which one of the two underground main mine fans was shut down to allow for shaft maintenance. Booster fan operation was not adjusted during shutdown, inducing recirculation in the studied mining district (Figure 7). The intent was to examine the state of the recirculation zone air quality during this upset condition, and also to examine uncontrolled district recirculation. Although the recirculation percentage approached 20% and the district fresh air supply was slightly reduced, total dust levels increased slightly and respirable dust levels remained low. Diesel particulate matter (DPM) levels increased modestly in line with the recirculation level, but still remained low.

#### 4. Summary of NIOSH Research Findings

National and international experience has shown that utilization of booster fans can effectively improve airflow to increase miner safety and health in normal and district recirculation applications [8][13][16][23]. Safety is enhanced through

application of new technologies as confirmed in coal mine AMS systems for intake belt air and in VOD systems. Leakage around the booster installation has the potential to recirculate return air contaminants, but at a low concentration if booster fan pressures are kept at moderate levels (250 Pa) and local stoppings are effectively sealed, especially if fans are installed in an outby location where mine ventilation pressure differentials are higher. At these outby locations, return air contaminants have been shown to often be much lower, further minimizing recirculation issues and improving air quality.

Modelling and planning are very important, with variations in modeling and pre-booster operation leakage noted due to stopping behavior being different when pressures in the return airway have changed due to booster fan over-pressure. Modeling must be calibrated with operational data and include fire scenarios to plan for booster fan shutdown, mine evacuation, and the effect on the circuit.

Increased inby airflow in both the booster and recirculation circuit can reduce main fan airflow and ultimately total fresh air flow to the area, which must

be taken into account as total fresh air is the key component for effective ventilation. Any null points

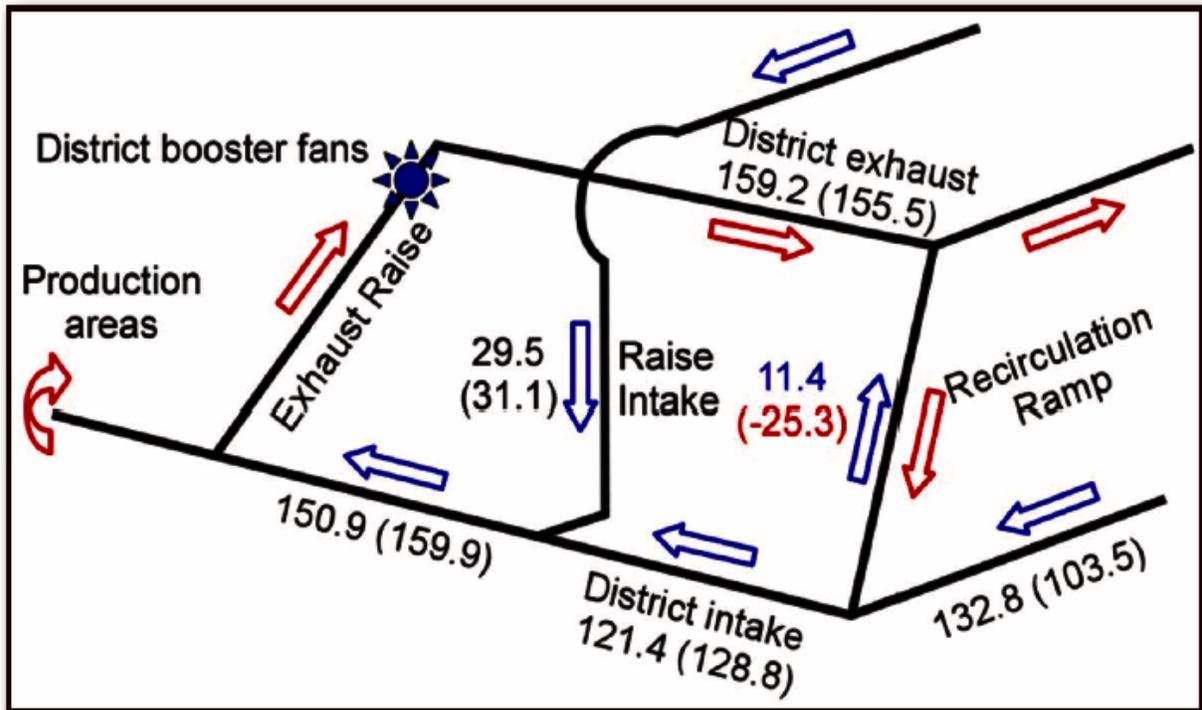


Figure 7. Survey Schematic – Airflow  $\text{m}^3/\text{s}$ : Normal (recirculation). Intake (blue), return (red).

which involve marginal or reduced flow zones must be managed to increase local flows or to include the option of using air doors, especially if actively travelled. Areas affected by booster fans require diligent monitoring of contaminants, fan performance, and airflow.

### 5. Operational guidelines and procedures for booster fan use

Booster fans must use proven methods to ensure miner health and safety during normal and abnormal operation, by utilizing successful techniques noted previously and incorporating monitoring and control technology. M/NM mines have begun implementing Airflow Optimization (AO)/VOD monitoring and control systems to optimize airflow and minimize energy consumption [29]. However, due to restrictions in airflow quantity changes when miners are underground [17] in 30 CFR 75. 324, the full capability of AO/VOD cannot be utilized in US coal mines and often in gassy M/NM mines. Refined technologies associated with AO/VOD have greatly improved the ability to monitor and control ventilation systems, increasing awareness of and potentially improving response to contaminants that affect miners' health and safety.

Operational issues noted with coal mine booster fans were reported by Gillies and Calizaya [23] showed that mines recirculated an average of 10% of the air, while Marlborough [36] stated that many air locks needed to be installed for safe personnel access due to increased pressure differentials. Leeming and Webb [13] concluded that booster fans were a beneficial addition to the ventilation system at large and deep coal and potash mines and that with correct standards, safety of personnel was not compromised. Operational guidelines and procedures noted in the above three references are a comprehensive guideline to good practices in operation of booster fan installations in coal and M/NM mines, in addition to those noted here. Extensive information from years of operating experience on fan system monitoring, controls, management and supervision, communication, training, and system shutdown is described, allowing the booster fan application to be tailored to the individual mine's needs.

M/NM booster fans can induce recirculation during operational upsets and as mining circuit balances change with mine development and seasonal natural ventilation variations. It is often normal practice for mining to take place in series or return circuits, where operations can be complicated by

these changes and booster fan use. Many of the above proven guidelines for coal mines from Leeming and Webb, and Gillies and Calizaya can be applied to M/NM mines, especially for monitoring fire contaminants and fan pressures, and for remote fan startup and shutdown.

Vigilance is required in mine work areas during main and booster fan maintenance with reduced system airflow. These conditions are addressed by performing additional personnel exposure and air quality monitoring procedures for contaminants such as carbon monoxide. When these situations are known in advance, ventilation modelling should be conducted to determine airflow changes and increased contaminant exposures, especially at critical work faces and in recirculation zones. Employees should be notified of system changes and their effects. Again, application of monitoring and control technology is a key component to optimize reduced airflow and ensure a safe and healthy mine environment.

Ventilation system complications from booster fan operation place a higher responsibility on management to educate and train affected employees in emergency procedures specific to the individual mine. As booster fan/AO/VOD systems are implemented, the reactions by persons supervising the AMS system or software programmed to control the system need to be well thought out and failsafe.

Potential hazards and risks such as harmful recirculation and fires can be mitigated by utilizing state of the art monitoring and control, employee training, maintaining ventilation expertise and dedicated management support. Regular assessment of the operational state of the booster fan system must be performed and adjustments made to assure minimal leakage and safe operation.

## 6. Conclusion

Booster fans have been successful in providing additional airflow to dilute contaminants and safely improve the mine environment in M/NM mines and international coal mines for many years.

The key advantage to booster fans is the timely manner in which they can be installed, improving airflow much more quickly over standard options such as upgrading main fan pressure which increases air leakage considerably, or additional ventilation shafts. Today, mining is intimately affected by the complex world economy, and mines are often started with minimal knowledge of total ore reserves. Reserves and mining areas often expand, challenging the ventilation system in meeting health and safety

levels. Booster fans can be an effective tool to combat these issues.

The other key ingredient to effective booster fan implementation is the recent improvement in monitoring and control systems technology, notably AMS and AO/VOD, adding a level of safety not available even a few years ago. Knowledge of the current state of the overall mine ventilation system, mine contaminants and individual fan operation allows miners and management to make informed health, safety and emergency decisions. This provides miners the best conditions during changing operations during the current shift or for short term mine planning challenges.

Utilizing technological improvements and international and NIOSH research results in combination with proven experience from successful international and domestic mining operations will result in booster fan applications that provide airflow improvements resulting in improved miner health and safety.

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## Disclosure

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company or product does not imply endorsement by NIOSH.

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