SAFETY, TECHNOLOGICAL, AND PRODUCTIVITY POTENTIALS OF HIGHWALL MINING

Jon C. Volkwein, Thomas P. Mucho, and Suresh K. Bhatt

U.S. Bureau of Mines
Pittsburgh Research Center
Pittsburgh, PA

ABSTRACT

The Bureau of Mines reviews developments in technology of auger and continuous highwall mining systems. Data collected from Bureau testing, mine visits, manufacturers, and the literature are used to survey the current status of highwall mining systems. A brief historical perspective of continuous mining highwall systems is presented with emphasis on currently operating systems. Included are discussions on worker health and safety and productivity issues such as ventilation, inertization, rib thickness monitoring, ground control, and coal extraction/haulage. Future highwall mining scenarios include the application of computer assisted continuous mining for better machine control. Improved methods for monitoring gas levels in auger mining are included.

INTRODUCTION

The safe, cost effective, and environmentally sound recovery of the substantial reserves of coal contained within highwall outcrops has long been a goal of the mining industry. The development of highwall mining and equipment has traditionally been confined to the U. S. and only recently have applications and equipment development been seen in Australia and South Africa(1). The U. S. Bureau of Mines (USBM) has estimated that there are 18,000 miles of highwall terrain in Appalachia. This constitutes a reserve base of 20 billion tons for highwall mining systems (HMS s) that are capable of 850 ft of penetration(2). Since much of this coal is categorized as low sulphur, the 1990 Clean Air Act Amendment has enhanced its value even further. Often these reserves are uneconomical to mine by surface mining methods due to the poor economics of increasing stripping ratios, and yet lack the extent to merit the investment required for deep mining.

In addition to providing a means to economically mine otherwise lost reserves, HMS s offer many advantages over other mining methods. A major benefit is that they limit environmental concerns, especially compared to other surface mining techniques. Also, this system of mining is adaptable to both large and small properties and, unlike deep mining, it requires no roof bolting, extensive ventilation, or other underground mine infrastructure. Worker staffing is lower compared to other methods with 2 to 3 people used for auger drilling and 4 to 7 people for most of the newer highwall crews. In spite of this, high tonnages (in the area of 100,000 tons or more per month in normal seam heights) are possible with many of the systems, especially with the improved technological developments. Future potentials for highwall mining hold even more promise, for, unlike other mining methods, highwall mining has not yet reached a mature stage of development(3).

Typical HMSs use either augers or continuous miners located and/or controlled from the bench of a previously surface mined area. They usually consist of a means to mine the coal by penetrating the highwall and a means to convey the mined coal back to the bench for loading. In the case of auger systems, the mining and conveying systems are combined. For all HMSs, workers are stationed on the bench. No artificial roof support is provided inside the usually parallel openings into the highwall. Instead, these systems rely on the speed of mining, the natural strength of the roof, intervening small pillars, shape of the opening, and a periodic larger barrier pillar to maintain the integrity of the opening until the full penetration and equipment recovery is complete. The machinery on the highwall bench is equipped with permanent overhead canopies for falling object protection at all work stations.

Production statistics for highwall mining systems are difficult to estimate due to the intermingling of highwall and surface mined coal at the surface preparation plants. Based on engineering estimates, current annual highwall mining production from both auger and continuous miner based HMSs is over 20 million tons.

BACKGROUND/HISTORY

Augers

The earliest method of extracting coal from a highwall was by auger mining (figure 1). Early systems, in use since the mid 1940s, used a single auger driven from the bench to penetrate the coal(4). The simplicity of the auger system is that it both mines the coal and conveys it back to the bench as the auger penetrates the coalbed. Auger systems can typically mine coalbeds of any thickness using cutting heads that range in size from 24 to 60 in. Thick coalbeds can be mined by aligning the holes vertically, one below the other. Single head systems produce a series of circular holes along the highwall. Later developments to combat the low coal recovery ratios included the use of double and triple headed auger systems which produce oval shaped holes. However, due to the shape of the openings and limited penetration distance, these systems offer low to moderately acceptable reserve recovery.

Figure 1. An auger type highwall mining machine.

Auger mining is attractive due to its ability to economically extract thin coal beds, high productivity, high mobility in and out of smaller jobs, relative independence from other surface mining activities, and reliability of augering machines. However, it also suffers from disadvantages due to the nature of the mining system. The lack of head guidance and the effects of gravity contribute to problems of controlling the path of the opening. Also, the mining/conveying activity of the system causes frictional losses along the entire length of the auger flights. This limits its penetration depths to a maximum of 500-

600 ft (normally 180 - 220 ft) and seam heights from 16 to 70 in (although a couple of companies are reportedly developing a 10 ft diameter auger for Australian conditions(5)).

There are currently two main manufacturers of auger mining machines in the United States. The best census estimates indicate that there are about 240 auger machines in worldwide operation. At any given time, however, a quarter to a third of this population is active. Improvements in auger mining machines have included increased power, automatic transmissions, enhanced bit and head design, and automated auger handling. Safety improvements have included canopies, blast deflection shields, and inert gas explosion suppression systems(6).

Alternative HMS s

Desires to overcome the disadvantages of auger mining and the development of continuous mining machines led to the development of forerunners of other types of HMS's seen today. These newer systems use a remotely controlled continuous miner coupled to some type of haulage system.

Carbide Miner. This concept was employed as early as 1950 when the Carbide and Carbon Chemicals Company introduced a HMS known as the "Carbide Miner"(7). A continuous miner using four overlapping borer-type cutting heads drove a 38 in by 9.67 ft opening with this system. The continuous haulage unit consisted of 30 ft long conveyor belt-type units that were self-propelled on rubber tires. A crane on the highwall bench added each unit to the train. Sensitized picks were used for vertical guidance, while a drill mounted on the miner was used to probe the rib thickness for horizontal guidance.

Push Button Miner. Joy Manufacturing licensed the Carbide system by the late 1950's and improvements resulted in the "push button miner" (figure 2) in 1961. Design changes included replacing the crane loading with a spiraled storage unit capable of storing 60 conveyor units and a secondary rotary cutter drum for adjustable cutting height. The system could penetrate up to 1000 ft and claimed tonnages of 2000 tons per shift, although 450 tons per shift seemed to be the norm. However, high cost, low reliability, special maintenance requirements, poor operator control design, and inadequate operator training resulted in unsatisfactory commercial success for this system(8). Its size (300 ton structure, 300 tons of cars) and the erection time (3 months) were also formidable factors that did not permit its widespread use, even though the concept was well advanced for its time.

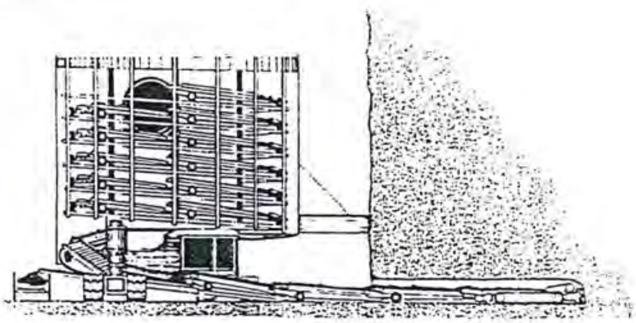
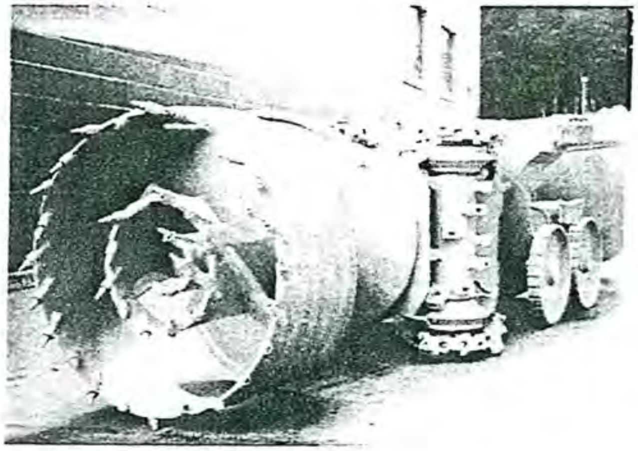


Figure 2. Push button miner concept.

Coaltex Edna Miner. The Coaltex Edna miner was first introduced in the mid-1970 s. It consisted of a auger type cutting head and auger flights for coal conveying (figure 3). In between these were two cutter wings which were folded in on advance into the coal but extended outward during retreat. As a result, it mined a 42 in by 42 in opening on advance that would be reamed to 84 in wide on retreat. Reported advantages to this system were that the cutter wings helped maintain a straight line of advance, ground control concerns were minimized by the narrower opening width on advance, and highwall stability could be aided by not reaming the immediate area near the surface opening.



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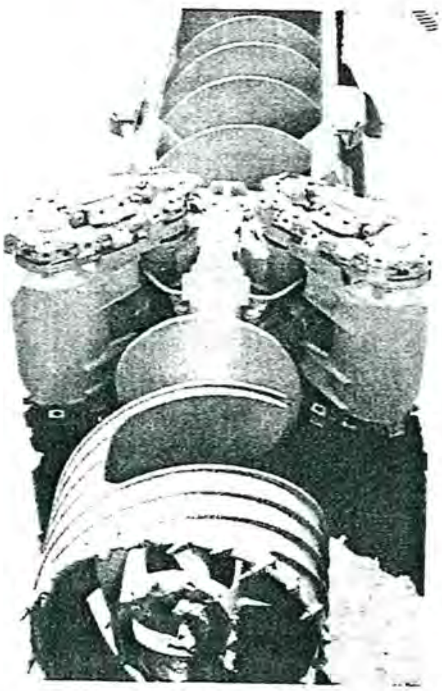

(3b)

Figure 3. Edna miner with wings positioned in (3a) for penetration and out (3b) for mining during extraction of the mining head.

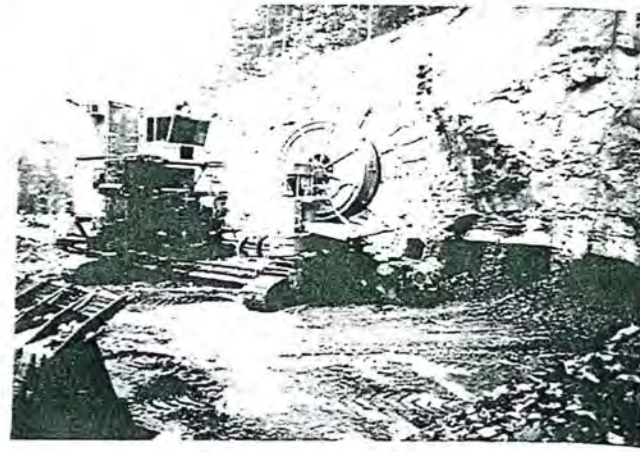

Figure 4. METEC highwall mining system.

Metec. The Metec Hi-Wall Miner, in figure 4, was introduced commercially into the U. S. in 1981. Originally a hydraulic system, an electric version was available in 1985. The Hi-Wall Miner uses a horizontal cutting head from 8 to 10 ft in width that shears the coal in an up and down motion and is thrust into the coal by hydraulic powered push beams. Coal is conveyed by horizontal counter-rotating twin augers mounted in the push beams that are 20 ft long and added as the machine is advanced in 20 ft sumping increments. To assist the operator in machine control, sensors are used to determine angle of the cutterhead, power usage to assess material being mined, and natural gamma radiation sensors behind the cutterhead to detect the thickness of roof and floor coal being left. The horizontal guidance is a function of the rigidly attached push beams. At present, about nine METEC or modified METEC type HMS's are active in the country.

Chandler Short Hole. During the late 1980 s, the Bureau worked with S. H. S. Inc., to develop the Chandler Short Hole System(9). Components of this system were a Jeffery 102HP thin-seam continuous miner (TSCM), a computer-based remote control system, and a multiple unit continuous haulage (MUCH) system developed by the Bureau. One microcomputer system located in the operator's station on the highwall was connected to another located on the continuous miner via cables along with the power and water conduits. Data transmitted on these cables included; the operator commands, video signal, and sensory information. Sensors included: 3 video systems, and hydraulic, temperature, current, sound, linear displacement, methane and heading sensors. Entry direction was provided by a laser alignment system.

Openings were 4 ft high by 11.25 ft wide and could be driven to a depth of 275 ft.

TramVeyor. During the late 1980s Consolidation Coal Company (CONSOL) began developing a "punch mining" system, illustrated in figure 5, for highwall mining. The system used the CONSOL developed TramVeyor mobile conveyor, an automated and remote controlled continuous miner, and a load out vehicle to discharge from the conveyor. This system is not currently operating in highwalls.

Addcar™. The most recent commercially successful addition to the HMS family was the ADDCAR™ system developed by Addington Resources, Inc., and currently marketed by Joy Technologies, Inc. under a 14 year licensing agreement initiated in 1992(10). Figure 6 shows the system that consists of a continuous mining machine, conveyor cars, launch vehicle and loadout facilities. The launch vehicle and loadout can be located on a highwall bench as narrow as 70 ft. Cascading rubber tire belt conveyor cars of 40 ft length are connected behind a Joy continuous miner within the launch vehicle. A fixed conveyor in the belly of the launch vehicle provides addition of conveyor cars without interrupting the mining process. The launch vehicle also provides hydraulic thrust to the train in addition to the crawler drive of the miner. Penetration ranges from 100 up to 1200 ft in seam heights from 36 in to 14 ft. The operator is situated in a control station on the launch vehicle and uses up to 6 water-jet washed video cameras for information to remotely control the continuous miner.

There are currently 14 ADDCAR™ type systems operating. One system is being employed in Australia in a "trench mining" operation. In this application, due to a gently dipping coal seam at this site, the increasing overburden eventually makes normal surface mining uneconomical. Therefore, periodic trenches are surface mined to the seam and the intervening coal between the trenches can be mined with the highwall system, permitting the economical recovery of these reserves without resorting to deep mining. A U. S. operation in Indiana is reportedly investigating the trench mining concept.

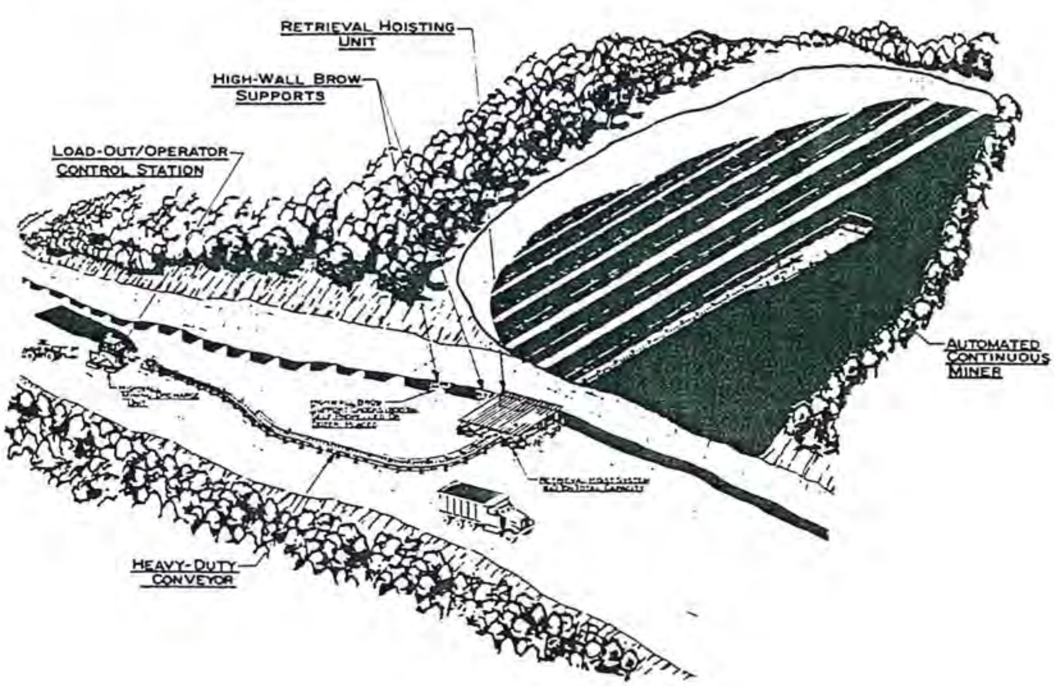

Figure 5. CONSOL's Punch Mining system.

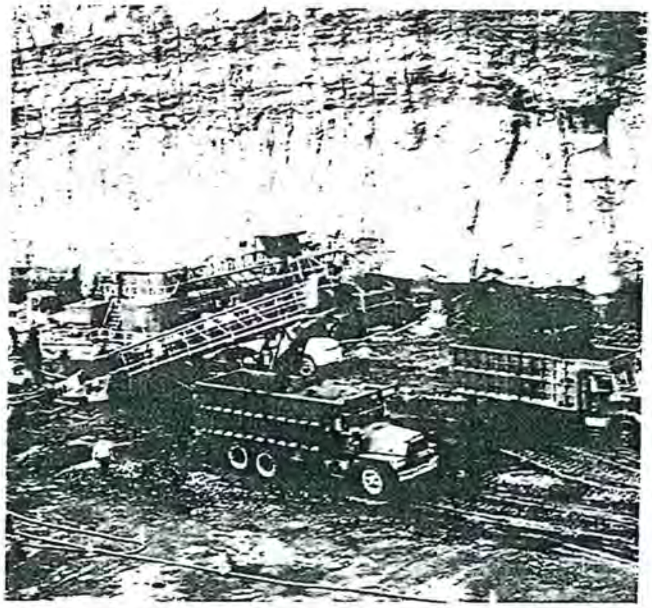

Figure 6. Joy ADDCAR™ highwall mining system.

Archveyor System. This highwall mining system employs a mobile conveyor continuous haulage system behind a continuous mining machine. A self-tramming mobile conveyor uses its bottom chain strand as a track. For conveying coal, the conveyor is raised on powered legs so that the bottom chain strand comes free of the floor. The coal is then transported on top of the mobile conveyor along the same path as previously trammed by conveyor. A surge bin is provided at the inby end of the haulage for additional capacity. The highwall mining system is remotely operated from a cab vehicle. The conveyor discharges coal for truck loading through a system of belt conveyors outside of the highwall opening. One such system is currently operating in the U. S.

TECHNOLOGY/SAFETY NEEDS

Ground Control and Highwall Stability

Many of the past HMS problems have been addressed with technological developments in machine design, improved conveying systems, and advancements in sensing and control. As a result, ground control may now be the leading problem facing successful implementation of continuous miner based HMS s, especially when mining deeper holes. Inability to control the ground results in a number of problems for highwall mining. Highwall stability has obvious safety and productivity consequences. Small falls of material from the roof can slow production, damage equipment (especially conveyors), and dilute the quality of the coal recovered. Large roof falls or major collapses can offer serious safety and productivity challenges. Elaborate techniques to insure worker safety must be employed to recover equipment that is trapped and not retrievable by remote means. This usually involves development of a supported opening(s) using an MSHA approved plan. While these events have been relatively rare (2 reported at one operation(11)), they underscore the need for a high level of ground control for HMS s.

Maintaining the integrity of the highwall is critical to any HMS for production and safety concerns. Parameters that affect highwall stability are highwall design features, age, lithology and other geological characteristics, and discontinuities such as jointing and hillseams. Stress relief and blasting techniques also play an important role(12). Many of these factors are dictated by nature and are not easily addressed. In one case, a highwall that was old, weathered, and had a clay layer angled from the top, failed and resulted in extensive machine damage and over one month of lost production(13). However, some progress in technologies have made highwalls safer and HMS s more viable. For instance, advancements in blasting technology, such as pre-splitting techniques, have contributed to highwall stability(14). There are those in the industry that feel that the abandonment of the Peabody "Hillseam Machine" in the mid 1960 s was a result of large ground failures due to less advanced blasting techniques used at that time. Advanced smooth wall blasting technology is especially critical to the success of trench mining HMS s(15).

In addition to using the most advanced techniques to insure highwall stability, today's HMS s use some common philosophies to address the issue. These approaches are to closely coordinate the timing of highwall mining to the initial surface mining and to protect and/or remove the workers from the hazard. The first approach is straightforward in that fresh highwalls are not as susceptible to the effects of stress relief, weathering, and general deterioration. The second approach is inherent in the design of the newer HMSs. For example, the CONSOL punch mining scheme uses highwall brow supports that can be remotely operated and a protective canopy for workers safety. Work structures that double as protective structures and relocating operator(s) to areas more remote from the highwall are features of other approaches.

The approaches to small and large falls of ground are similar in that both are a function of various ground control principles and ground control techniques. Factors especially affecting ground control for HMS s are: opening size and shape, thickness and uniformity of intervening and barrier pillars, roof rock disturbance, seam thickness, strata lithology and geology, overburden thickness, multiple seam effects, depth of penetration, rate of mining, and the general mining plan.

One of the advantages of the auger type HMS is the creation of circular openings which create very stable arch shaped entries. However, the circular geometry reduces the level of recovery in low seams, theorectically 52 pct with 12-in webs with 24-in diameter augers and 67 pct with 12-in webs with 72-in augers.

The change from small, circular openings to wider, rectangular shaped openings, created by continuous miner HMS s, increases the difficulties of ground control. Therefore, greater reliance and importance is placed on the other ground control factors noted. Mined opening widths of the newer HMS s center around the widths of current continuous miners (9 1/2 - 12 ft). In some instances where poor roof quality exists, reduction of opening width to 9 1/2 ft is the first and most effective ground control measure. Some geology is not conducive to these large openings. However, where applicable, common experience has shown that widths in the 9 1/2 - 12 ft range are usually compatible with current mining rates, depth of penetration, and the natural stability of the opening, given the geology of most U. S. sites.

Time is another variable that can positively influence ground control. High, uninterrupted production rates reduce the exposure to unstable or deteriorating ground conditions. In all mine plans, machinery is removed from underground at the end of the day.

Coal-Rock Interface Detection

Other recent technological developments and ongoing work will improve ground control. Disturbing the roof rock, for instance, can lead to small or large roof failures. Therefore, in-seam guidance systems that can delineate the coal-roof rock interface are critical advancements. Some of these coal-rock interface detection (CID) systems rely on vibration, power usage, natural gamma radiation detection, infrared thermography, spatial domain radar, x-ray florescence, or electron spin resonance. A reliable CID system offers significant economic and safety advantages. From an economic standpoint, higher coalbed extraction can be achieved by reducing the requirements to leave excess coal for ground control purposes. This also results in reduced dilution of the mined material by minimizing the amount of roof/floor material cut, and a higher value per ton. Production rates will increase because more time is available for coal cutting and maintenance will decrease due to reduced machine induced vibration. Less cutting of quartz bearing roof or floor rock will improve miner health and safety by reducing the airborne quartz dust levels. Bureau efforts in coal rock interface detection are particularly focused toward research on the infrared technique, a noncontacting electromagnetic (radar) sensor, and vibrational techniques(16). These technologies for HMS s have additional mining applications as well.

Rib Thickness

The thickness and uniformity of the intervening pillars between openings also impact the ability to control the ground and optimize reserve recovery. For the HMS s that use larger openings, common practice is to leave approximately 4-ft rib pillars between openings, with a periodic barrier pillar of approximately 20-ft between sets of openings (usually 5). Given these parameters, a theoretical recovery rate of 58 pct is possible. As seam height increases, however, rib thickness requirements generally increase. While past experience has shown that this is generally a reliable system, the roof geology, seam height, multiple seam effects, overburden thickness, and mining rate need to be considered when developing the mining plan. The mining plan also must consider support rib and barrier pillars at "points" where the highwall is exposed on three sides.

Rib pillar thickness control is a special problem for HMS s. Due to the remote mining guidance method, knowledge of the location of the mining machine and determining rib thickness have been particular areas of technological development for the systems. The manufacturer of one system has estimated that about 1 in every 25 holes will intersect a previous opening(17). The Bureau continues to develop an advanced rib thickness determining system which should even further increase the ability to control the ground.

A sensor developed by the Bureau can identify reflections from both sides of the rib to give the machine operator an accurate idea of rib thickness. The noncontacting electromagnetic sensor utilizes a ground penetrating radar, SIR-10 (by Geophysical Survey System, Inc.). It is a commercially available pulse-type system having full digital control. The system provides instant continuous-profile records in color to indicate the thickness of strata within the subsurface of the earth. This Bureau system was tested at two highwall sites in the U. S. and provided successful results(18).

Ventilation

Highwall mining technology has progressed to the point where it now approaches an underground mining method. Underground mining safety considerations such as ventilation for methane control are still required and may be more important in the absence of direct human observation. The need for these safety considerations was illustrated in November 1991 when an Addcar™ highwall machine had a fatal ignition accident(19). As a result of this accident, methane detectors and blast shields were required on the mining machine. In the event that methane was encountered, ventilation was to be used to dilute the methane to an acceptable level. The ventilation system that is currently used consists of a 1600 cfm diesel powered air compressor. Air is delivered to the face through a continuous, flexible 3-in pipe that is stored on a reel on the launch vehicle. At full delivery volume the air compressor requires 440 hp at about 22 gph of fuel consumption. In practice, only 8 gph of fuel is used which calculates to about 1000 cfm of air actually delivered by the ventilation system.

Auger machines have encountered similar ventilation problems, including several non-fatal ignitions. These ignitions have been reported from a number of seams in various regions. MSHA has used "imminent danger" authority to close several operations when concentrations of methane were detected at the collar of the auger holes. The auger mining method does not easily lend itself to ventilation since the auger generally fills the entire cross section of the mined opening. This makes it difficult to establish separate intake and return air paths. The center of the drill steel provides one option for a ventilation path, however strength considerations limit the open area in the couplers to less than one inch. Furthermore, on long holes, the integrity of over 60 separate connections between auger sections must be guaranteed. Blast shields provide some protection of the operators and were initially recommended by some MSHA offices as an interim solution to the hazard.

However, none of these solutions were practical. The Bureau of Mines developed, tested and implemented a method of using inert gas to prevent methane ignitions. This method, illustrated in figure 7, relies on the removal of coal as the impetus for the movement of inert gas into the hole. Gas placed at the collar of the hole precludes the formation of explosive methane/air mixtures. This technique is currently being used on at least 6 auger machines mining in seams that have previously experienced ignitions.

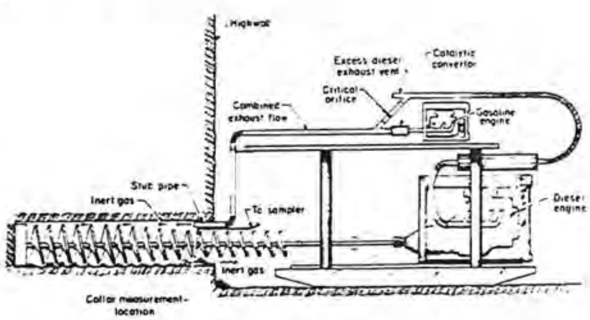

Figure 7. Inert gas method of explosion prevention.

A Bureau of Mines study investigated the ventilation needs of the Metec highwall mining machine. This machine uses push beams that enclose a dual opposed auger conveyor to remove coal. The Bureau study of this system used sulfur hexafluoride tracer gas to show that the enclosed dual augers provided a separate return air path and, in effect, screwed return air away from the face with the coal. Data indicated a ventilation flow of about 200 cfm was occurring with this system(20). This small air ventilation volume is adequate to dilute small methane liberation rates of up to 4 cubic feet per minute.

Other safety considerations must still be addressed as technology improves the ability to remotely control underground mining equipment from the surface. These considerations include:

1. Methane Dilution Capacity. The maximum volume of methane that a given ventilation system can handle to maintain compliance with existing underground ventilation regulations.

2. Dust Explosion Prevention. The ability to prevent dust explosions with either rock dust or other inerting technology.

3. Fire Prevention. Fire detection and/or prevention in the absence of humans.

4. Monitoring for Engineering and Legal Purposes. Monitoring for adequate air flow and methane concentrations or for maintenance of inert gas concentrations.

All of these safety considerations are adequately controlled using the Bureau developed inert gas technology which has applications beyond the auger mining method. For example, the Addcar™ mining method would require about 200 cfm of inert gas that could be produced on site using only 4 gph of diesel fuel. Demonstration of this approach on that particular type of machinery is required to prove the feasibility of the concept.

FUTURE DIRECTIONS

Because of the increasing productivity of HMS s there is a growing need to monitor gas conditions within the highwall excavation. A new method of monitoring gas levels in auger highwall mining is being developed by the USBM to determine the presence of methane or to determine the effectiveness of the inert gas approach. Figure 8 shows a prototype method used to evaluate these gas conditions. This system currently provides a historical record of the gas conditions during mining, however, this technology is intended to form the basis for a real-time operator readout of gas conditions during mining.

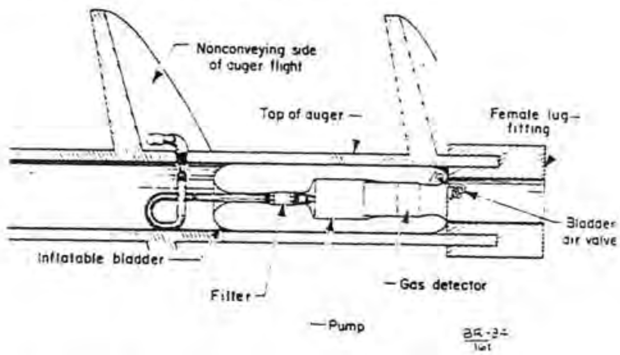

Figure 8. A prototype in-hole gas monitoring method for auger type machines.

Parallels exist between the new generation of highwall mining machines and the underground developments in the greater use of automation, deeper remote control cutting, and continuous haulage. Cross-fertilization of ideas from highwall to underground are beginning to occur. For example, the Bureau/Chandler concept has been expanded with Computer-Assisted Mining and includes a continuous mining machine and continuous haulage system. The scenario envisions adding computer-assisted control to existing highwall mining and haulage systems. For additional safety, the operator compartment is situated on the mine bench out of direct line of the highwall mining entry (figure 9). The operator(s) is able to control all functions of the mining and haulage, cutting, tramming, etc.--through visual, aural, and other displays in the operator's compartment using proven computer technology. This system would be equipped with state-of-the-art technologies such as vertical and horizontal guidance, equipment status diagnostics, and strata condition sensing/monitoring, which both the industry and government are interested in pursuing on a continuing basis.

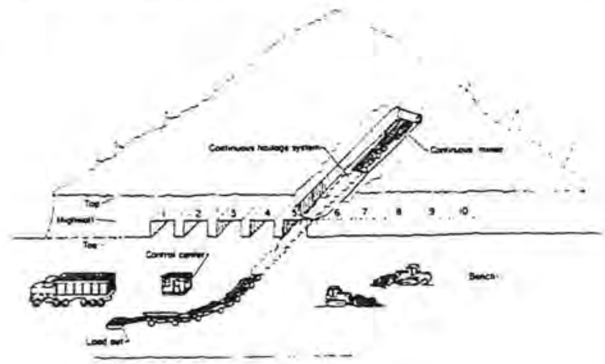

Figure 9. Computer-assisted continuous mining/haulage scenario.

Worker health, safety, and productivity go hand in hand. The control room is a controlled environment, and provides protection from air contaminants, falls of highwall materials, and explosions. An operator located in a safe, clean, and relaxed environment is subject to less tension or fatigue and, therefore, is able to work with greater safety, efficiency, and accuracy (21).

A computer-assisted mining/haulage system will enhance mining productivity because of reduced system downtime, thereby increasing available operating time, and reduced mining cycle time, resulting in mining more coal per shift. The Bureau has successfully demonstrated the operation of a continuous mining machine under computer control. These results will be integrated with a computer controlled continuous haulage system. The development and successful implementation of these technologies bode well for continued growth in highwall mining.

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Published by the Department of Mining and Minerals Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0239
703/231-6671