Enhanced Gob Gas Recovery

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INTRODUCTION

A gob, or gob area, is a region of fractured geologic material from overlying strata that has settled into mined-out areas after coal recovery. The overlying and underlying material relaxes after shortwall or longwall mining operations have passed by, as shown on Figure 1, or after pillar removal with the room and pillar mining method, as shown on Figure 2. Gas volumes liberated by gob areas into the mine ventilation system depend on the method of mining, the number and proximity of overlying and/or underlying gas-bearing strata, their reservoir characteristics, and other geological factors. The primary motive for gas recovery from the gob is to reduce methane emissions into mine workings and assist the mine's ventilation system in providing a safe environment for coal exploitation activities.

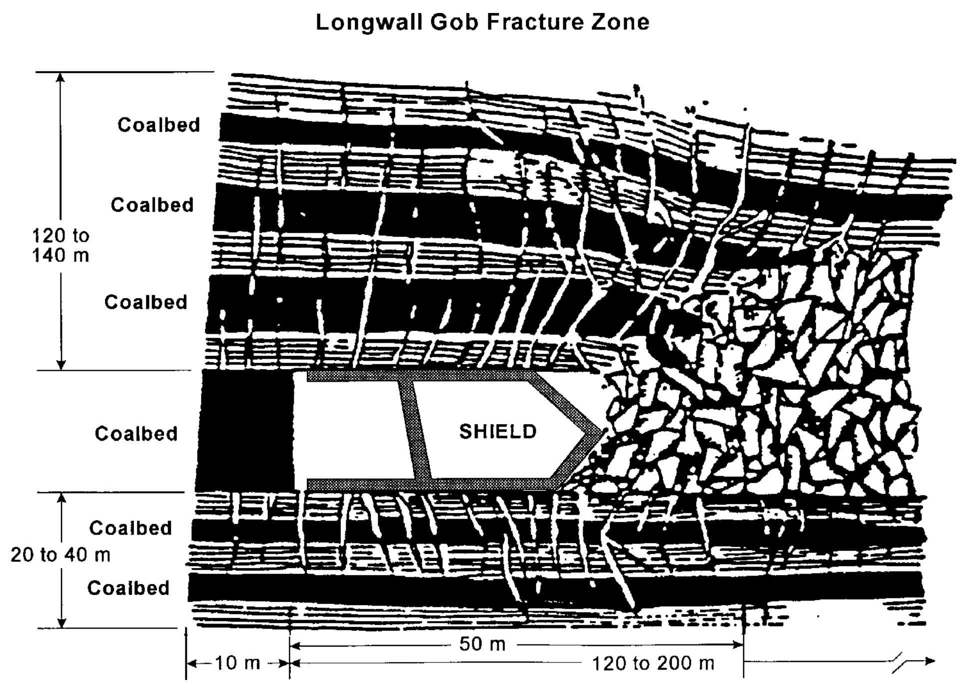

Figure 1. Side view of the effects of longwall mining on adjacent strata (Cervik, 1979).

At most mining operations, much of the gas emitted from the gob discharges to the atmosphere, either directly from the recovery system or through the ventilation system. Gob gas recovery systems may produce high-quality gas depending on conditions, but generally produce gas with lower methane concentrations. Poor recovery may be due to the nature of the resource itself, or may result from focusing attention on minimizing gas emissions into the mine ventilation system. However, there is potential at many mines to increase recovery and decrease dilution levels by adopting improved degasification and collection systems and by modifying operating practices.

There are three primary methods of longwall gob degasification that are used worldwide, and mining operators often adopt variations of these: *cross-measure boreholes, superjacent methods* (where degasification takes place from overlying or underlying galleries and boreholes), and *vertical gob wells*, as generally illustrated on Figure 3. The purpose of this paper is to encourage improved gob gas recovery and collection with these methods by presenting low-cost, best practices that may increase methane capture with less intrusion of mine air. Most of these practices cost little or no more than traditional and less effective practices.

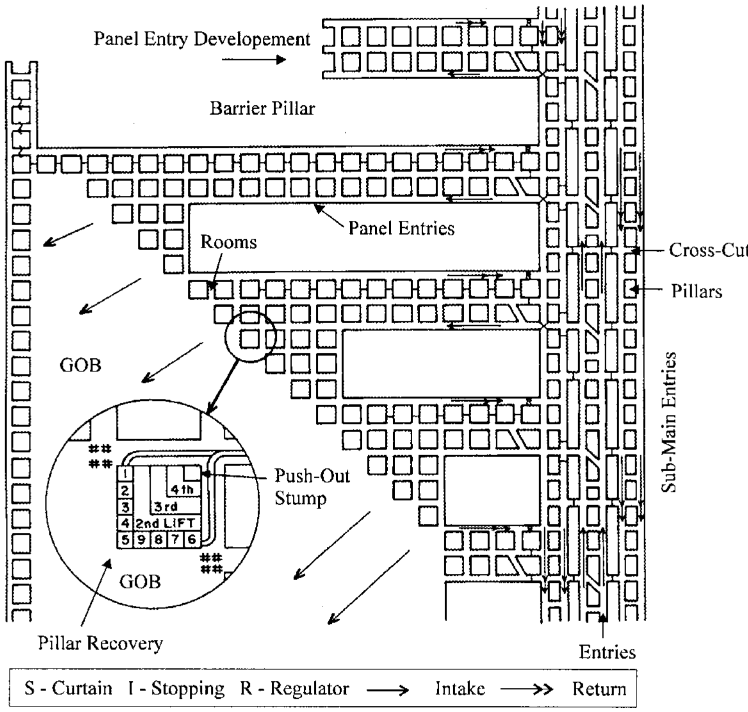

Figure 2. Plan view of a typical room and pillar mining panel in the U.S. (Stefanko, 1983).

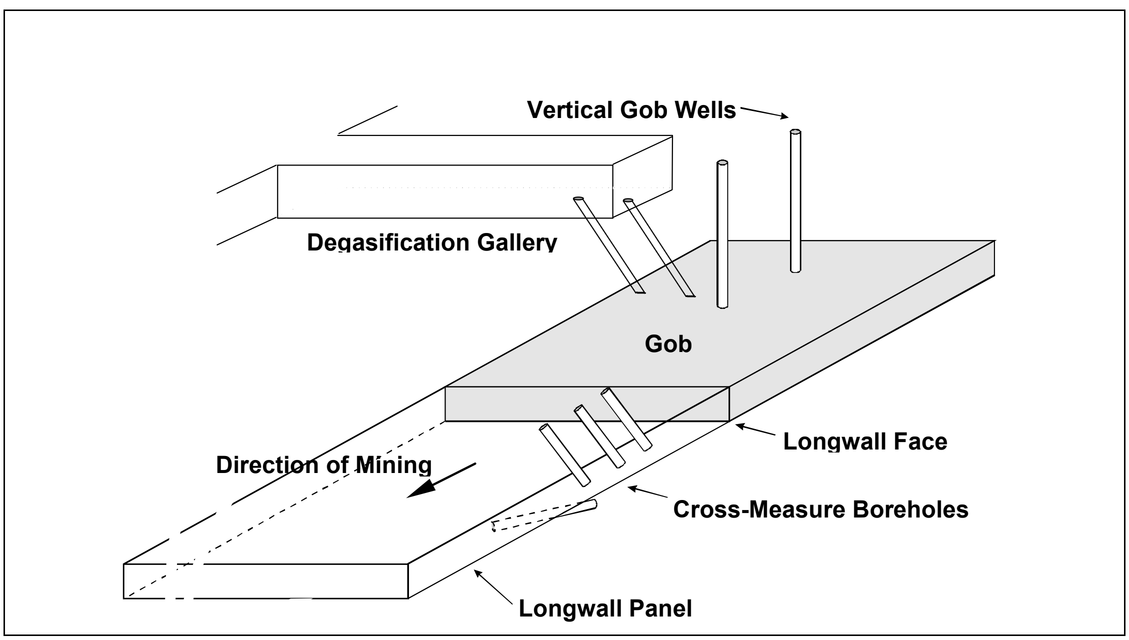

Figure 3. Schematic showing the different gob gas recovery methods.

CROSS-MEASURE BOREHOLES

Description

The cross-measure technique of longwall gob degasification is the dominant method used in Europe and in the Commonwealth of Independent States (C.I.S.), where operators practice longwall mining in multiple dipping coal seams, normally deeper than 600 meters (m). Several U.S. mines have tested cross-measure boreholes (Cervik and King, 1983) and found them effective where operators could not implement vertical gob wells because of surface constraints or other conditions.

With the cross-measure technique, small diameter boreholes (50 to 100 millimeter (mm) diameter) are drilled at angles from gateroad entries up into overlying or down into underlying strata, in advance of the longwall face, as shown generally on Figure 4. In extremely gassy conditions, operators place boreholes from the intake as well as the return entries surrounding the panel. Site-specific conditions dictate the angle, length, and spacing of the boreholes. In order to maximize connectivity with the gob and minimize inflow of mine air into the degasification system, operators insert and seal a pipe (commonly known as a standpipe) into the initial borehole length.

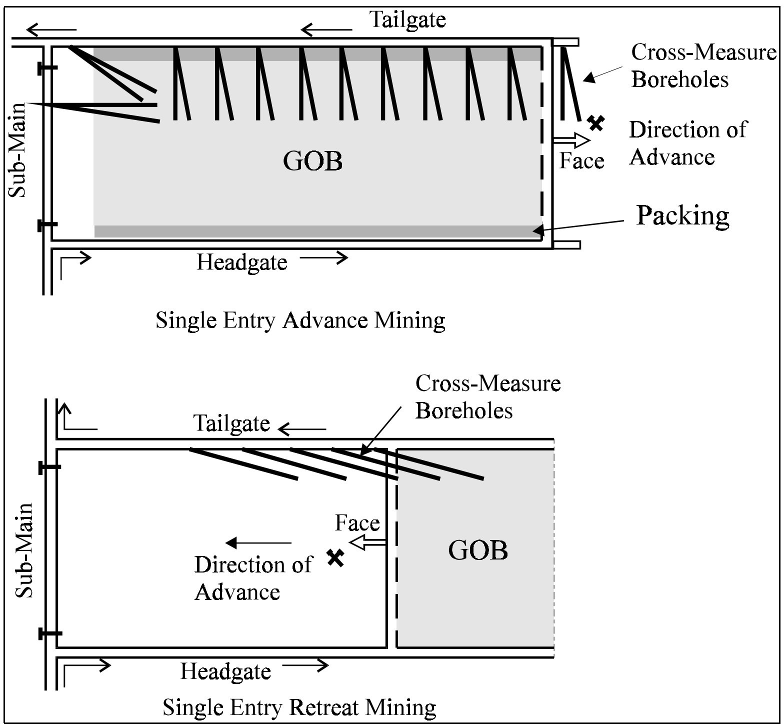

Figure 4. Cross-measure boreholes for longwall gob gas recovery for advancing and retreating operations (Wisniewski and Majewski, 1994).

Single-entry gateroads that parallel the gob for advancing longwall operations retain their integrity because operators always support them well. Therefore, it is fairly simple to maintain cross-measure boreholes and the gas gathering system. However, this becomes a concern with retreating longwalls, because the gateroad entries adjacent to the gob collapse upon retreat. For single entry retreat mining (performed outside the U.S.), there are two cross-measure borehole variations, as shown on Figure 5. Both systems provide access to the cross-measure boreholes and a protective environment for the gas gathering system. The upper figure shows a retreating system where two gateroad entries are developed in advance of mining along one side of the panel to accommodate the degasification boreholes. The lower figure shows an additional entry developed as the longwall panel retreats.

Cross-measure boreholes connect to a gas collection manifold that is normally under suction induced by a vacuum pump. Suction (negative pressure) is the primary means of controlling the gas flow rate from cross-measure boreholes.

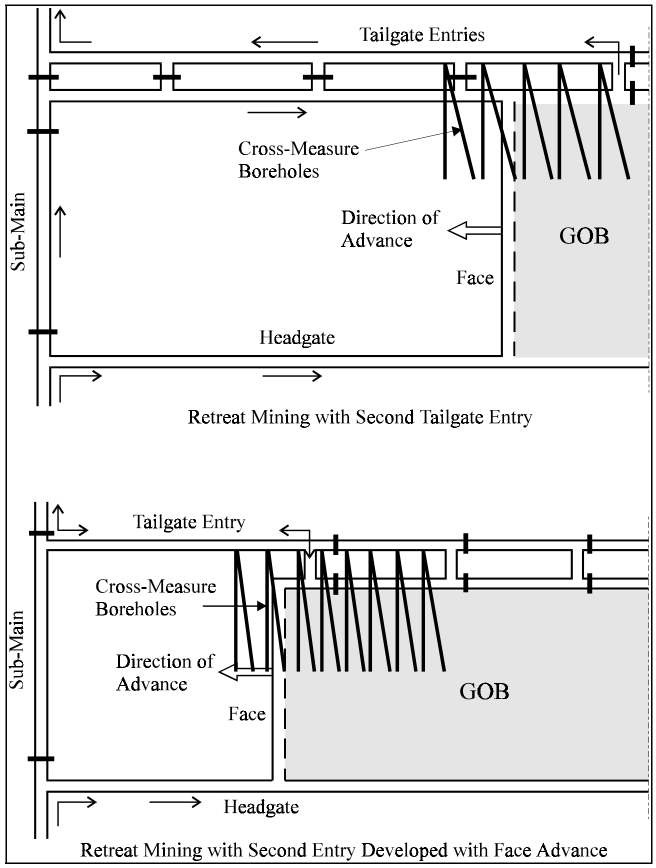

Figure 5. Cross-measure boreholes developed from a second entry for longwall gob gas recovery for retreating operations (Wisniewski and Majewski, 1994).

Best Practices in Cross-Measure Borehole Technique

The objective of cross-measure gob degasification is to provide a continuous low-pressure zone above the mined coalbed in order to minimize the emission of methane into the mine openings. The continuous low-pressure zone promotes not only downward migration of gas from overlying fractured strata, but also upward migration of mine ventilation air and gas released from the rubble zone in the gob. Methane capture efficiencies, defined as the ratio of the gas captured by the degasification system to that emitted into the ventilation system plus that captured, range from 20 percent to 70 percent with the cross-measure borehole technique (McPherson, 1993). Lower gas purities are typical with this system because of the number of boreholes and the connectivity between the boreholes and the ventilation system. The following low-cost practices may improve gas production and/or recovered gas quality for this technique.

1. *Site Boreholes to Maintain Integrity:* The cross-measure borehole collar location is critical to its performance and to recovered gas quality. Because fracturing tends to occur along the entries adjacent to the longwall gob as the face passes, it is desirable to protect the integrity of cross-measure boreholes developed in this region. If connectivity exists between the borehole and the mine ventilation system, wellhead suction pressure will tend to draw in air from the mine ventilation system, rather than gas from the gob, resulting in poor gas quality. With retreating

longwall systems, where multiple entries are used, researchers recommend initiating the borehole over the immediate adjacent pillar line to provide additional protection from the nearby fractured environment. Operators should avoid cross-cuts as they are susceptible to fracturing after the face passes. With advancing systems, operators should install additional roof supports, such as substantial packing walls, arches, etc., at the immediate borehole location to assist in protecting the initial length of the boreholes. The practice results in improved borehole stability, thus preventing intrusion of air and improving the gas quality. Borehole integrity is critical for recovering high-quality gas. For retreating systems, the additional incremental cost of this practice relates to the added drilling required (i.e., between 20 and 40 percent) depending on projection requirements and dimensions of entries and pillars. As drilling costs are approximately 60 to 80 percent of the cost of installing this system, the estimated incremental additional costs of this practice are between 10 and 30 percent. For advancing systems, operators may avoid incremental increases in costs by siting the boreholes near adequately supported packing walls or near supports. Benefits of this practice are increased system efficiency and improved gas quality. Depending on baseline conditions, this practice may improve recovery efficiencies by an estimated 20 to 40 percent and recovered gas concentrations by an estimated 10 to 20 percent.

2. *Grout Borehole Collars:* Maintaining standpipe integrity is crucial to borehole productivity and recovered gas quality, because system suction will promote intrusion of mine ventilation air through inadequate standpipe seals. This factor contributes significantly to the low qualities of gob gas recovered by many cross-measure installations. Good sealing requires proper construction techniques and materials. Successful cross-measure installations use good quality plastic or steel casing at least 6 m in length secured by grouting in place. Results of U.S. Bureau of Mines (USBM) studies suggest that standpipe grout annuli of 20 mm are effective in the cross-measure borehole technique (Garcia and Cervik, 1985). Operators may pump the grout into the standpipe and extrude it through the annuli, or feed it directly into the packed-off annulus with a system of grout supply and air relief tubing. The practice results in a significant improvement in the prevention of intrusion of mine air near the collar. In the case of advancing systems, where the life of a degasification borehole is much longer, the practice would also serve to increase the productive life of the well. Therefore, the overall benefits are increased gas production duration and improved gas quality. Estimates of the incremental cost of this practice range from 10 to 15 percent. Improvements in recovery efficiency and recovered gas quality depend on baseline conditions; however, operators may achieve benefits similar to those possible by proper siting (Practice 1, above).

3. *Increase Vertical Angle:* The cross-measure borehole should target the farthest known gas source and be angled so that its farthest extent is situated in the fractured zone above the rubble after the gob is formed. If the borehole extends only to the rubble zone, it will be prone to drawing mine ventilation air, thus impairing its effectiveness and gas quality. In trials of the cross-measure technique in the U.S. (three conducted by USBM), vertical borehole inclinations ranged from as low as 21 degrees to as high as 37 degrees (Cervik and King, 1983). The upper limit of vertical inclination depends on the width of the longwall panel, depth below surface, thickness of the mined seam, site-specific geomechanical properties of the strata, drilling space available, and limitations of the drilling equipment. U.S. studies and European experience indicate that boreholes at higher vertical angles have a longer productive life and tend to produce purer methane. However, for every gob there is an optimum angle, and exceeding it will impair the borehole's performance. This optimum must be determined and implemented. The incremental cost of implementing this practice is minimal (relates to increased borehole length). Benefits of this practice are improved recovery efficiency and improved gas quality. Again, depending on baseline conditions, operators may realize improvements of between 20 to 40 percent in district recovery efficiency and 10 to 20 percent in recovered methane concentration.

4. *Increase Horizontal Angle:* In European mines, as well as U.S. field trials, typical cross-measure boreholes in retreating longwalls angle toward the faceline on the horizontal plane. Studies have shown that most of the gob gas (up to 75 percent in USBM tests - per Garcia and Cervik, 1985) emits from the newly fractured strata and stress relaxation zone directly behind the faceline.

Operators should angle the boreholes to intercept this zone with the holes' farthest point of projection. This orientation is especially important from single-entry gateroads used with retreat mining because of the need to maximize production within the borehole's finite life span. Once the face passes the wellhead, the access to the borehole is lost, and the well is normally shut in. U.S. field trials of the cross-measure technique used horizontal angles ranging from 45 to 60 degrees. For advancing systems, cross-measure boreholes may be driven at less acute angles to the faceline. The "relaxed" zone has higher permeability, and in the case of retreating systems where the life of the well is somewhat limited, the practice results in higher gas production. The incremental cost of implementing this practice is minimal (also relates to increased borehole length). The benefits of this system are particularly significant for single-entry retreat systems where district degasification efficiencies may increase by an estimated 20 to 50 percent, depending on baseline conditions.

5. *Shorten Horizontal Projection:* USBM tests of cross-measure systems along return gateroads show that a borehole's horizontal projection over the longwall rib does not need to be very long. In fact, 30 m horizontal projections were sufficient to obtain capture efficiencies of 71 percent with this system (Garcia and Cervik, 1985), and data indicated that shorter holes would have been as effective. Implementing this practice may, in fact, result in some cost saving related to reduced hole length without any loss in gas production rates.

6. *Test Adequacy of Well Spacing and Suction Pressure:* In order to produce a continuous low-pressure zone over the gob using the cross-measure system, the boreholes must be spaced such that their influence zones overlap slightly. If boreholes are too far apart, then the accumulated gases between boreholes will tend to migrate toward the nearest mine entry. If the boreholes are spaced too close together, they may promote migration of mine ventilation air into the gob, reducing the quality of recovered gas. USBM studies have shown that for U.S. conditions, borehole spacing of 60 to 75 m is adequate. The spacing required, however, will also depend on the available suction pressure at the wellhead and the gob permeability. Operators should test the adequacy of borehole spacing by shutting adjacent boreholes and observing gas quality changes and impacts on methane concentrations in the district return. This test assists in determining optimum borehole spacings and suction pressures, the two most important factors affecting gas production rates and gas quality with cross-measures. The cost of implementing this practice would derive from the time and effort required to shut in the well and to monitor the gas quality and methane concentration in the mine return. There may be additional cost associated with providing the ability to vary the suction pressure. Optimized cross-measure systems can recover up to 70 percent of gob gas emissions in a district.

7. *Decrease Borehole Spacings at Ends of Panels:* Research studies show that decreasing borehole spacing near the start and ends of new panels (or adding new boreholes to an existing configuration) to accommodate the gas generated in these large strata tension zones significantly improves the production of gas. Because the tension zones are more fractured, the permeability is higher and higher gas flow rates and capture efficiencies are achievable. Studies indicate that panel ends contribute to approximately 35 percent of total gob gas recovered by methane drainage systems (Diamond, 1995). Operators must weigh the cost of developing additional boreholes with the benefits of increased recovery. Depending on panel length, halving the borehole spacing at the start and ends of panels can increase cross-measure implementation costs by 30 percent. If these efforts serve to recover 70 percent of the gob gas generated from panel ends, versus assumed baseline conditions of 50 percent, this practice can lead to an increase in cumulative gas recovery of 15 percent for the longwall panel.

8. *Provide for Monitoring:* Because the degasification system operates in conjunction with the ventilation system and mining operations, it is important to provide coordinated management (using measuring instruments, monitoring, controls, and good communications) to optimize each of the three functions. Modern wellhead configurations enable measurement of gas quality, gas flow rate, and pressure. Figure 6 shows low-cost provisions for suction control and pressure and flow monitoring for a cross-measure wellhead. Operators measure the pressure differential

across the venturi to compute gas flow rate, they monitor the gauge pressure from the tap inby the venturi to determine static pressure, and they obtain gas samples through the taps via a vacuum to determine gas quality. Operators may use hand-held manometers or diaphragm gauges for the pressure measurements. This capability is useful for optimizing all of the factors that affect the performance of cross-measure systems, and for determining which boreholes to shut-in (shut-in values range from 25 percent methane in the U.S. to as high as 40 percent in some European operations (Thermie, 1994)). The direct benefit of this practice is ensuring that the quality of recovered gas is above the limiting value for the mine, while the indirect benefits are obtaining a reliable record of the gas quality and quantity and enhancing safety. Costs for hand-held, portable monitoring equipment and provisions for pressure monitoring and gas sampling are minimal relative to the costs of implementing cross-measure systems mine-wide.

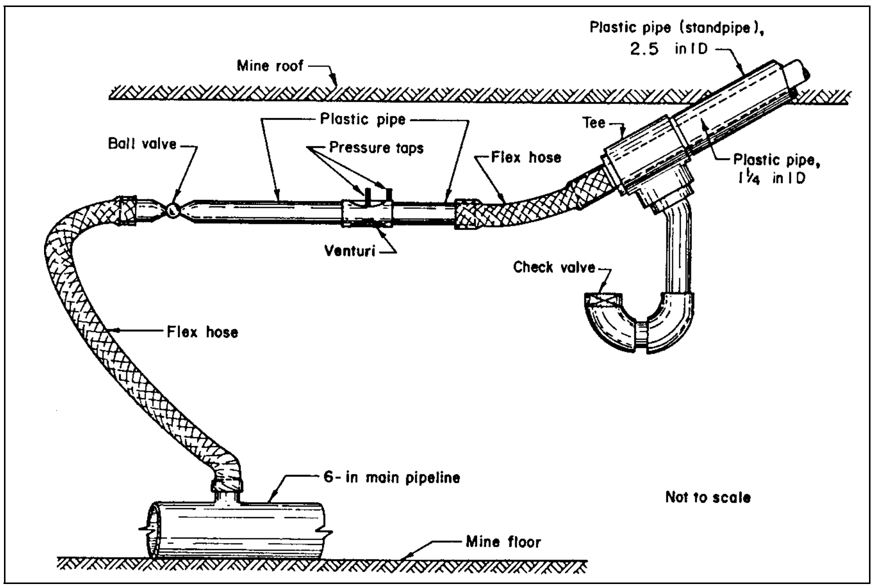

Figure 6: Cross-measure borehole wellhead configuration with monitoring provisions (Garcia and Cervik, 1985).

9. *Provide for Water Separation at Wellhead:* Water tends to collect in cross-measure boreholes developed over the mined seam directly above the wellheads and creates a need for a separation system. The USBM developed a water removal system for cross-measure boreholes (Garcia and Cervik, 1985), as shown in Figure 7. Water flows down the annulus between the production pipe and the standpipe and discharges from a one-way valve, mounted as indicated on the figure. The production pipe recovers gas through slots along its upper extension and delivers it to the collection system. An end-cap assembly prevents cascading water from entering the gas production line. Operators applying this approach may realize an estimated 5 to 15 percent increase in implementation cost, depending on baseline practices (such as use of grouted standpipes). Operators that have problems controlling water accumulation at wellheads may realize significant benefits in gas recovery with this practice.

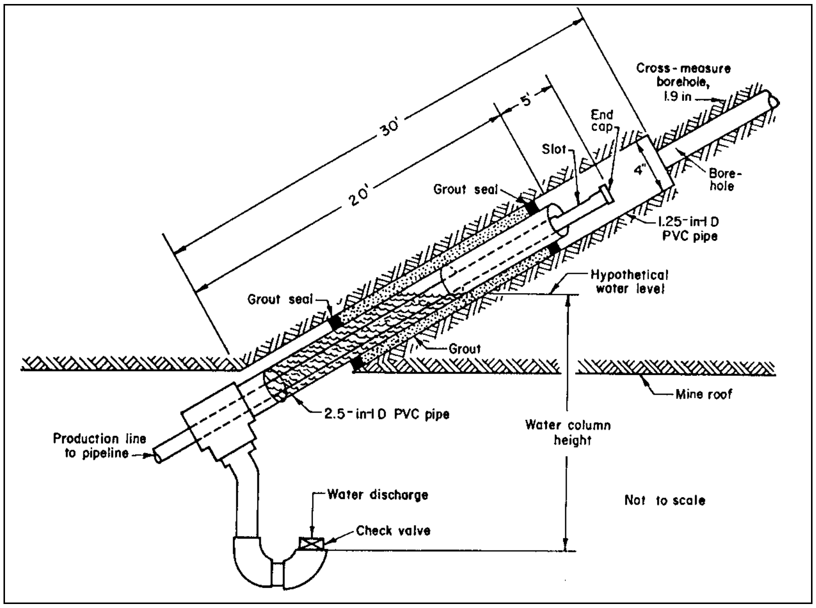

Figure 7: Cross-measure boreholes water separation system (Garcia and Cervik, 1985).

10. *Maintain Access to Wellheads:* In order to optimize system pressure control underground, mine personnel must be able to access the gathering line and valve heads. Retreat mining systems with single-entry gateroads do not provide for this under normal circumstances, and retreat systems with multiple entries may require additional supports along the pipeline to ensure access and pipeline integrity. Operators should consider this practice if there is the potential for significant gas recovery over long periods of time after the face has passed the borehole area. Research indicates that gob methane drainage systems may recover large volumes of gob gas (in some cases 50 percent of total recovery) after longwall mining is completed, depending on conditions (Diamond, 1995). With cross-measure systems, this practice requires appropriate prior planning on the part of operators and may require costly measures that operators must weigh against the significant increase in overall gas production and improvement in gas quality.

THE SUPERJACENT TECHNIQUE

Description

Some gassy, deep underground operations in eastern Europe, the C.I.S., China, the U.S. and Australia recover methane using the superjacent technique. The objective of this technique is to develop long drainage boreholes or galleries in advance of mining in overlying or underlying strata (rock or coal). In some cases, operators also develop small-diameter, short boreholes extending from galleries into strata overlying the gob. Overlying galleries serve as useful platforms for targeting the fractured zones over longwall gobs. Figure 8 illustrates two superjacent gob drainage techniques used in eastern European mines.

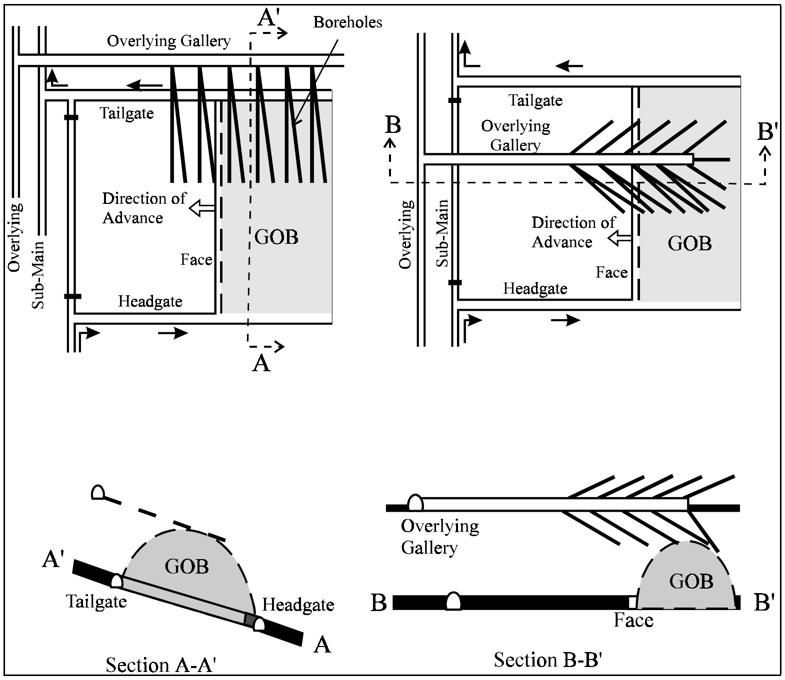

Figure 8. Degasification of gob areas using the superjacent method in Eastern Europe (Wisniewski, 1994).

Figure 9 illustrates the application of superjacent horizontal boreholes for initial premining degasification of an underlying coalbed and subsequent use for gob degasification as implemented in Australia. Operations in Japan, China, and the U.S. also use superjacent boreholes. The technique involves the use of in-mine directional drilling equipment, usually to develop 75 to 100 mm diameter boreholes to lengths in excess of 1000 m.

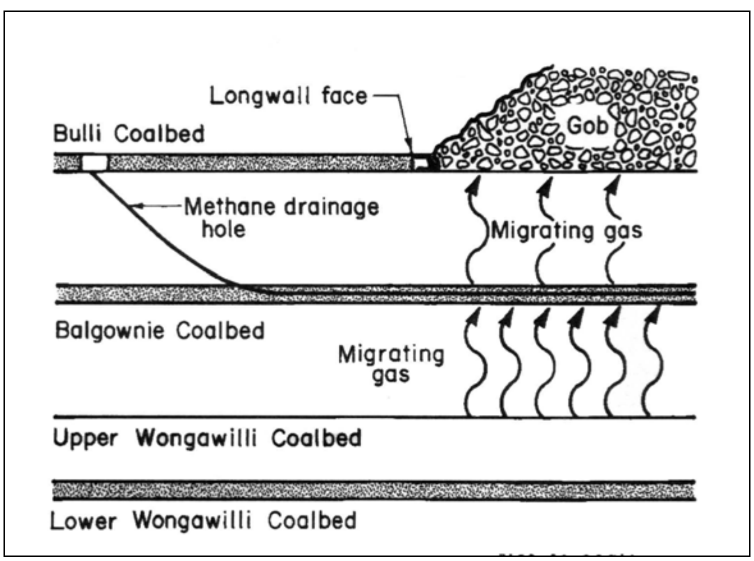

Figure 9. Superjacent borehole drilled into an underlying coalbed in Australia (Diamond, 1993).

Best Practices in the Superjacent Technique

The objective of gob degasification with the superjacent technique is to provide more immediate and independent access to overlying strata that will fracture as a result of longwall mining. The system enables the operator to place galleries and/or boreholes from non-production areas that are free of equipment- and production-related inconveniences. It also facilitates placement of boreholes in advance of the mining face for both advancing and retreating systems. Generally, operators using superjacent methods claim methane capture efficiencies of up to 80 percent (efficiencies as high as 90 percent have been reported (Liu and Bai, 1997) with superjacent galleries). As with cross-measure boreholes, gob gas drainage efficiency and gas purity for superjacent systems are affected by geologic and reservoir conditions, orientation of the galleries and/or boreholes, size and spacing, gallery and borehole integrity, suction control, and mine ventilation. The following low-cost practices may improve gas production and/or recovered gas quality for this technique.

1. *Target Boreholes and Galleries Appropriately:* To determine appropriate gallery and borehole placement in plan and in profile, operators must consider the geomechanical characteristics of the strata, the fracture characteristics of the gob as it forms, the resulting gob permeability, the proximity of source seams to the mined horizon, the system of ventilation, and the structure of the mining seam. To improve gas production (increase production time), operators should target galleries and boreholes below the contributing source seams and above the rubble zone to take advantage of the connectivity provided by the fracture network and this region's stability (relative to the rubble zone). Superjacent boreholes and galleries should target high-permeability tension zones along the perimeter of the panels, and consider gob gas migration patterns caused by the mine's ventilation system or the structure of the coal seam (grade), to improve gas recovery rates. There is no additional cost in implementing this practice. Operators applying this practice may realize substantial benefits in gas productivity and gas quality. Research indicates that gob gas recovery systems that target tension zones recover between 30 and 50 percent more gas than systems sited along the center of longwall panels (Diamond, 1995).

2. *Monitor Suction Pressures and Gas Concentration:* Operators will need to apply a vacuum to collection systems connected to superjacent galleries and boreholes to produce gob gas. In all applications of the superjacent technique, operators should carefully monitor and adjust gas collection system suction pressures and should measure the methane concentration of the collected gas and that in the district returns to optimize gob gas recovery and quality. Operators can perform this in a low-cost manner by monitoring pressures and gas concentrations with hand-held equipment on a scheduled basis, as necessary. Depending on baseline conditions, the primary benefit of monitoring and controlling suction pressures is improved gas quality; however, operators also may improve recovery using this practice. Depending on baseline conditions, this practice may increase recovered gas quality by an average of 20 to 40 percent.

3. *Develop Fewer, Larger-Diameter Superjacent Boreholes or Boreholes from Galleries:* To develop a continuous low-pressure zone over the gob, operators should develop superjacent boreholes at appropriate sizes and spacings so that borehole influence zones overlap slightly. As with the cross-measure system, if boreholes are insufficiently sized and spaced too far apart, gob gases will tend to migrate to the mine entry. If boreholes are over-designed and too close together, they may promote migration of mine ventilation air into the gob. Fewer, farther-spaced, larger-diameter boreholes may recover more gas at lower pressure losses than smaller-diameter, closely-spaced holes. Operators should use the Weymouth formula to assist in selecting the optimum borehole diameter (i.e., the capacity increases as a function of the diameter raised to the exponent of 2.667) for any given production rate and pressure differential (anticipated gob gas pressure minus inlet suction pressure). Applying this practice results in less drilling, fewer wellhead connections, minimized leakage, and improved system operation and control if there is a direct tie between the wellheads and the collection system. The benefit of the practice is an improvement in gas production rate and quality, increasing the system efficiency and ease of maintenance. Mine operators should weigh the extra cost incurred in drilling larger-diameter

holes, which might even require different equipment and/or larger galleries, against the incremental benefit of up to an estimated 20 percent in gas production and improved quality. .

4. *Maximize Use of Directional Steering Capability to Minimize Water Problems and Increase Borehole Surface Areas with Superjacent Boreholes:* Collected water from upper strata and drilling fluids can inhibit gas production, particularly for boreholes developed to target seams below the mining elevation. Similar to cross-measure boreholes developed below the working horizon, these holes may not produce gas until the water migrates through fractures that will develop during mining without water-lifting provisions (compressed air lift, for example). With longer horizontal superjacent boreholes, as shown on Figure 9, deviations in borehole trajectory can produce water collection areas (“U” shaped low-elevation zones) that impede gas flow. Using the steering capability of the directional drilling equipment, operators can minimize such water problems. They can develop a multitude of deviated, tangential boreholes from a single initial superjacent borehole. They can vertically control borehole undulations to avoid water accumulations in low areas, or they can develop tangential down-grade water control branches from the main borehole. Once the main borehole has reached the desired horizontal level, operators should (1) develop horizontal boreholes in a general downgrade direction, and (2) develop deviated holes in order to enlarge the zone of reduced pressure over the gob. This practice increases the extent of the low-pressure horizon over the gob, and mitigates water accumulation problems that may impair gas production. Because this practice may avoid some subsequent parallel boreholes, it may offset the additional costs of drilling to control water accumulation. Operators that experience water accumulation problems will benefit significantly from this practice, as this problem is otherwise only resolved when adequate gas pressures can move the column of water. This practice provides for earlier use of the borehole to reduce in-situ gas contents or produce free gas, and may increase cumulative production by an estimated 10 to 15 percent, depending on conditions.

VERTICAL GOB WELLS

Description

The predominant gob degasification technique applied in the U.S. involves vertical wells developed from the surface in advance of mining. As with all gob degasification techniques, the methane quality and quantity produced from these wells vary and depend upon site-specific geological and reservoir characteristics, and upon mining, degasification, and ventilation practices at the mine.

The usual practice is to drill large-diameter (up to 300 mm) vertical gob wells in advance of mining to within 10 to 30 m above the working coal seam. Operators case and cement the wells to a point just above the uppermost coal seam or gas-bearing stratum believed capable of liberating gas as a result of longwall mining. They leave the lower portion of the well open or complete it with slotted casing as shown on Figure 10.

Operators apply a vacuum to the gob wellhead to enhance production. At some mining operations, excellent production rates and high gas qualities are maintained with suction and proper monitoring and control. An example of such an operation is the Jim Walter Resources mines in Alabama, where overlying gas-bearing strata of high gas content are present, and where gob permeabilities are very high. Methane production and mining activities are closely coordinated. The Jim Walter Resources facility has implemented a system to carefully monitor gob gas collection and process it for pipeline injection. At most U.S. mines, however, the gas is not pipeline quality and vents from vertical gob wells directly to the atmosphere.

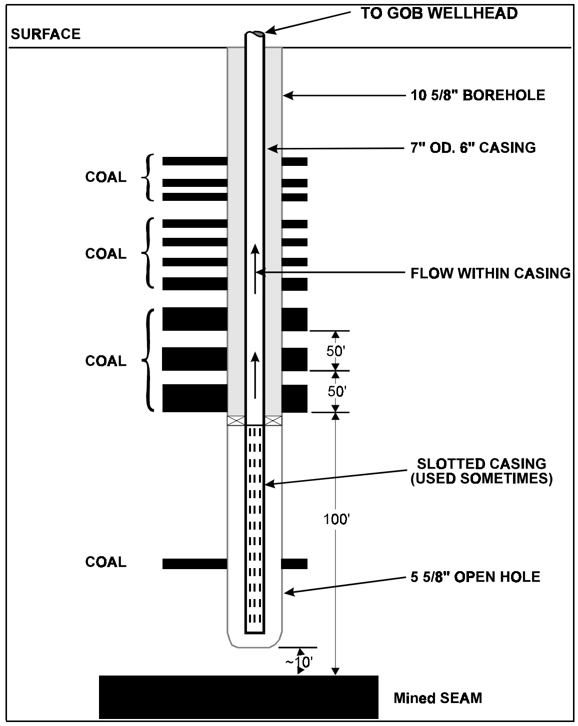

Figure 10: Profile of a typical U.S. vertical gob well *(dimensions in U.S. units).*

Best Practices in Vertical Gob Well Technique

Operators who use vertical gob wells in favorable geologic and reservoir settings have claimed high methane capture efficiencies. Mining operations with overlying gas-bearing strata exhibiting high gob permeabilities have been able to obtain high gas purities with this system. As with all gob gas recovery methods, intrusion of mine ventilation air is common because of connectivity in the gob between the borehole and ventilation system. Several factors (e.g., geologic and reservoir conditions, mining characteristics, well siting, completion practices, wellhead operations, and the mine ventilation system) affect gas capture efficiency and gas purity. The following low-cost practices may improve gas production and/or recovered gas quality for this technique.

1. *Install Wells in Advance of Mining:* Operators have not had much success with vertical wells drilled into gobs developed after longwall mining (Li et al., 1997). Operators that drill in advance of mining encounter better conditions to properly drill and complete an effective gob well. Benefits are considerably higher gas production rates at no or lower implementation costs, depending on baseline conditions.

2. *Provide Flexibility in Plans for Subsequent Wells:* Gob well performance records indicate that well productivity is linked to the dynamic creation of the gob and is dependent on the volume of coal extracted. At many U.S. operations, gob gas production rates depend on the longwall face advance rate. Operators have reported a two- to three-fold increase in gob gas production rate with increased longwall face productivity. Typically, operators select a location for the first well on a panel and evaluate its production record to help locate the subsequent wells. To successfully apply vertical gob wells, operators should ensure that there is flexibility to decide upon the exact well locations shortly before drilling. Benefits are higher gas production and improved gas quality at low or no incremental cost.

3. *Target Stress Relief Zones:* USBM studies indicate that gob well location significantly impacts gas production (Diamond, 1995). Records typically show that the wells positioned at the start and end of panels produce the most gas. This occurs because these wells intercept the strata within the zone of tension between the barrier pillar (at the start and end of the panels) and the two adjacent pillar lines. Because of the aspect ratio (the ratio of length over width) of the longwall panel, the tension zones at the ends of the panel are typically much greater than those alongside the pillar lines paralleling the panel. It is in the tension zones where the fractures generated by longwall mining activity tend to maintain their aperture, and where gob permeabilities are the highest. Gob wells located within the tension zones produce gas at higher flow rates and for greater durations than wells positioned along the centerline of panels. As indicated by tests conducted in the Lower Kittanning Seam in Pennsylvania, offset wells produced 30 to 55 percent more gas than centerline wells on a cumulative basis. Operators can typically achieve this benefit with no incremental cost.

4. *Experiment with Shorter Completions:* U.S. mine operators normally complete gob wells in advance of mining at depths to within 10 to 30 m of the mining seam. Experimentation is normally required to optimize vertical placement of each well. Some U.S. operators have noted that shorter completions, say 30 m above the mined seam, produce as effectively as completions that are much closer to the mined seam. In a case where the Pittsburgh seam is mined in West Virginia, measurements of gas inflows within the boreholes indicated that the intervals directly above the mined coal produced essentially no gas (Mazza and Mlinar, 1977). The benefit is cost savings without compromising gas production rates or gas quality.

5. *Use Surface and Slotted Casing:* A high-performance gob well must maintain wellbore integrity as well as connectivity with the fracture zone. Gob well completion concerns include vertical placement of the well within the gob, maintaining well integrity and productivity after undermining, and isolating water-bearing horizons. Water-bearing strata must be isolated from the well and mine workings by proper well-casing cementation practices. In some cases, significant water inflow is unavoidable and may worsen after mining because of increased conductivity exhibited by fractured strata (Diamond, 1995). Water collection will impede gas production. Some non-U.S. coal operators have not had much success with this technique because of completion practices. Wells that are completed mostly "open hole" and extend into the rubble zone may encounter water problems or shear after undermining, which limits the productive life of the well. Proper surface casing to isolate surface water-bearing zones avoids water accumulation, while slotted casing minimizes the potential of shearing and a short productive life. The benefit is a significant increase in gas recovery at estimated incremental costs of between 30 and 40 percent, depending on baseline conditions.

6. *Use Active Extraction with Local Monitoring:* Vertical gob wells will generally produce gas without applying suction due to their great elevation difference, but usually not until they are approached by the mining face. Some shut-in wells may exhibit positive pressure increases. Values as high as 40 kPa gauge have been recorded in Appalachian operations (Mazza and Mlinar, 1977). However, vertical gob wellhead operators have attained significant increases in gas production and methane reductions in the mine ventilation system with just slight vacuum pressures. In some cases, operators have noted a three-fold increase in production rate with application of a -6.9 kPa (1 psi) suction pressure (Mazza, Mlinar, 1977) to gob wellheads. Operators should determine (by monitoring) an optimum suction pressure that achieves underground gob gas drainage objectives and minimizes the introduction of mine ventilation air. This requires careful monitoring of gas quality and the ability to adjust the vacuum pressure promptly. The result of this practice is a significant increase in gas production; however, if the system is not implemented correctly, it may result in poor gas quality. Depending on local drilling and completion costs, this practice will increase gob well costs by an estimated 30 to 50 percent (with local monitoring provisions).

7. *Monitor Continuously to Achieve High Recovery and Gas Quality:* Wellhead operations, ventilation controls, and mining operations are widely separated with the vertical gob well system. Therefore, it is important to have effective tools to manage the impacts of each system on the others. Because of the gob wells' effect on the mine ventilation system (particularly if gob ventilation is required, as in the U.S.), operators must closely coordinate these two systems with continuous monitoring. Continuous monitoring is particularly imperative to maintain gob gas quality for projects that use the recovered gas. Operators should employ systems that indirectly measure methane content, as these are less costly. This involves obtaining continuous oxygen monitoring data from the wellhead, calibration data from nitrogen samples taken periodically at gas gathering points, and a formula to extrapolate the results. Oxygen sensors are accurate, less costly, and readily obtainable. A central control facility can collect data by FM transmission, and computers with programs updated with calibration data can conduct the extrapolations. Ideally, methane concentration information collected by sensors in the longwall districts would supplement the surface information, and operators would have the ability to make adjustments whenever necessary. The benefits of this practice are improved gas quality and increased gas production; however, it is not a low-cost practice and is presented herein only for completeness.

8. *Effectively Seal Mined-Out Areas:* Some U.S. operators recover large volumes of gob gas (up to a half of a gob well's cumulative production) after they complete longwall mining. These operators seal the mined gob areas from main mine ventilation air courses to minimize leakage and to increase ventilation system efficiency. This practice also mitigates the occurrence of "heatings" in cases where operators are concerned with spontaneous combustion. Effective sealing of gob regions can improve recovered gas quality. Operators can more effectively seal mined-out areas by reducing the number of seals necessary to isolate the gob from active workings through use of large coal pillars (barrier pillars) or by implementing more effective sealing methods. Operators would need to incorporate this practice into their mining plans and must weigh the implementation costs with the benefits of improved gas quality. In cases where lower coal extraction ratios are the result, or a large number of "effective seals" are required, operators may not consider this practice low in cost.

ENHANCED UNDERGROUND GOB GAS COLLECTION AND TRANSPORT

An integral component of a mine degasification system is the gas collection and transport infrastructure. Underground, this infrastructure serves to move methane collected from degasification boreholes up to the mine surface or to a dedicated underground dilution area. On the surface, gathering infrastructure ranges from vertical in-seam gas collection wells to compression and processing facilities. This section focuses on *underground* gob gas collection systems that are typically more difficult to control and maintain than surface systems because of mining activity and the complex subsurface environment. Gas collected from underground gob degasification boreholes comes to the surface via a network of pipes fitted with safety devices, water separators, monitors and controls, and vacuum pumps.

Components of an Underground Gas Collection and Transport System

Pipes: A gob borehole normally connects to a collection line via a flexible hose. Collection lines transport the gas to a main gas line, which leads to a vertical collection well that may be freestanding or affixed onto the lining of an exhaust shaft. Pipelines are steel or high-density polyethylene (HDPE), where permitted. Steel lines are preferred for mechanical strength, especially for the underground to surface connection, but HDPE is easier to handle and is non-corrosive. Pipes are either suspended or laid on the mine floor. U.S. guidelines stipulate that a methane drainage pipe should be in return airways, visible along its entire length, not submerged at any location, and pressure tested during installation.

Safety Devices: Safety devices installed along the pipeline network serve to protect the infrastructure from leakage during pipe ruptures. Operators typically install automatically activated safety shut-off valves at each borehole and along the piping network at enough locations to sectionalize the system during failure conditions. The valves are activated pneumatically or electrically by means of methane sensors in the airway, pressure sensors, or protective monitoring tubing devices (which are common in the U.S.).

Water Separators: Operators install water traps, or separation devices, at low elevations along a methane drainage network so that water (condensate, or formation water) will not impede gas production. Operators typically use large water separators at wellheads and at the base of the vertical collection well as shown on Figure 11. These devices subject the gas to a sudden expansion that reduces its velocity, dropping the entrained water droplets. After separation from entrained water at the wellheads, gas mixtures are typically saturated with water vapor.

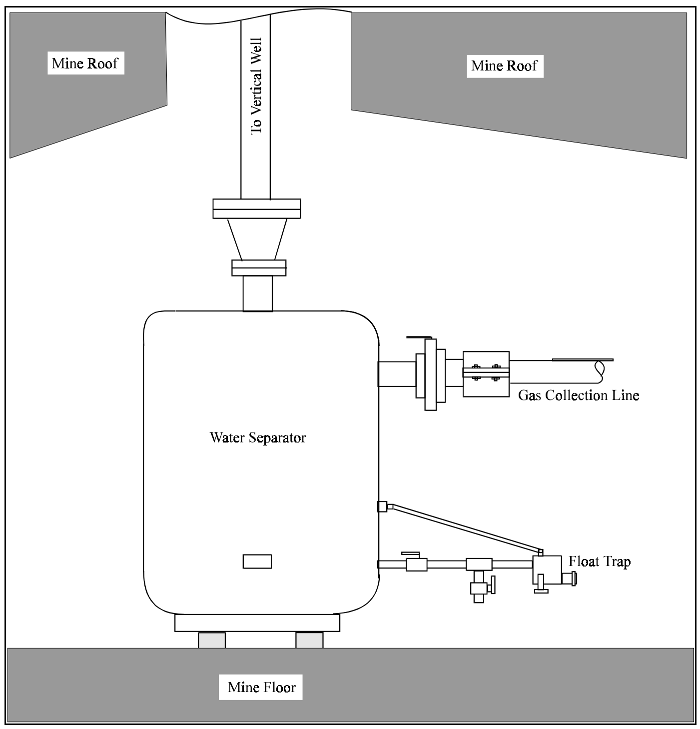

Figure 11. Separation system at the base of a vertical collection well.

Monitors and Controls: Gas collection system monitors sense three parameters: pressure, flow rate, and concentration of gas constituents. Valves activated either manually or remotely by pressure, gas quality, or flow sensors comprise the control system.

Gas Movers: Gas moving equipment includes extractor pumps and compressors. There are three types of systems that are most prevalent for supplying negative line pressures to a degasification pipe network: water seal extractors, centrifugal blower/exhausters, and rotating pumps. Water seal extractors are preferred for installations underground because of the inherent safety features of producing a vacuum, since these do not significantly increase gas temperature and do not require contact between stationary and moving parts (McPherson, 1993).

Best Practices in Underground Gob Gas Collection Systems

The following are practices in underground gob gas collection systems that would improve safety and assist in improving gas production rates and gas quality.

1. *Use High Density Polyethylene (HDPE) Piping:* Air leakage into a negative-pressure gas collection system affects recovered gas quality and system performance. Leaks are most common with carbon steel pipes because they are susceptible to corrosion and require threaded or gasketed connections. Gasketed, flanged fittings tend to leak over time, particularly when exposed to the mine environment, or when operators frequently move or strike the pipeline. Welding the pipe sections and fittings in advance of placement reduces leaks, but inevitably, because of access limitations, welding constraints underground, and handling difficulties, flanged connections are required. The primary arguments against the use of HDPE piping in the U.S. are related to material strength and static electricity discharge. These reasons have limited its acceptance in underground mines worldwide. The material strength concern was overcome in the U.S. after rigorous testing (Energy Applications, 1976). To prevent static electricity problems, all HDPE lines in U..S. mines must be grounded with a wrapping of 10 gauge copper wire along the entire pipe length and by appropriate connections to ground. In this way, operators may use HDPE piping, where permitted, and take appropriate precautions. Use of HDPE prevents leakage as operators may fuse rather than flange together pipe sections as well as pipe fittings. Its lighter weight facilitates handling, and it is noncorrosive and requires less maintenance than steel pipes. The benefits of this practice are improved production through increased suction pressures underground and improved gas quality by mitigating leakage at pipe joints and fittings. Operators may offset the increased capital cost of HDPE (costlier for larger diameters) with cost savings gained in installation and maintenance. Depending on conditions, operators may realize increases in recovered gas quality as high as 50 percent with HDPE systems versus flanged steel pipe networks.

2. *Monitor Pipe Integrity:* Impact tubing makes it possible to monitor the integrity of the entire gathering line. It is a small diameter, mechanically weak tubing that is affixed to the gas collection line and pressurized by an inert gas such as nitrogen. Operators should connect this line to actuators fitted on isolation valves at boreholes and along collection piping. The monitoring tubing would break on impact to the collection line and would activate appropriate isolation valves. This practice makes the operation safer and avoids unforeseen accidents resulting from rupture of tubing. This practice would increase the installed cost of an underground gas gathering system by 30 to 40 percent, depending on baseline conditions.

3. *Sectionalize the Gathering System:* Operators should sectionalize their underground gas gathering systems to limit methane release after pipeline breaches. U.S. guidelines suggest sectionalizing to limit methane releases to 28.3 m^3 per 4.7 m^3/s of ventilating air flowing in the entry containing the pipeline (U.S. Department of Labor, 1978). Operators should apply this practice with Practice 2 above.

4. *Provide for and Maintain Adequate Water Separation:* Accumulation of water is common either at the wellhead or along gas gathering lines, and this is a major cause of poor gas production. Uncontrolled accumulation of water occurs when entrained water separators, traps, or scrubbing devices cannot properly drain, or if the pipelines are aligned without consideration for water drainage. Operators should remove water accumulation at wellheads, at lower elevations along the pipeline, and at the base of vertical collection wells with the use of automatic water trap systems. Operators should use float traps (modified to account for negative pressure) to release water while preventing air intrusion, or water dumping systems if operating at high vacuum. This practice would increase the installed cost of an underground gas collection system, but would systematically reduce the cost of operations and greatly enhance system performance.

5. *Monitor the Gathering System:* Negative pressure applied at the wellhead affects gas production and quality. High suction pressures tend to introduce mine ventilation air, while insufficient suction may impair production and increase methane emissions into the ventilation system. Pressure monitoring and control capabilities at the wellhead are critical to proper production control for the entire system because pressure responses are specific for each borehole. Operators must achieve proper pressure control through strategic placement of control valves

within the system, employing sufficient wellhead monitors, and properly designing the vacuum pump and gathering system. Frequent monitoring of static pressure and orifice plate flow meters installed near gas movers and at critical junctions underground will help operators to optimize system performance and will inform them of increased system demands. Operators could implement this practice with daily inspections for minimal incremental costs. Benefits are improved system performance and increased recovered gas quality.

SUMMARY

This paper presents best practices for gob degasification to increase gob gas production and improve recovered gas quality. Specific effective, low-cost practices can improve productivity and gas quality at existing systems. The practices cover a wide range, including borehole (well) siting or placement considerations, borehole integrity, water separation, gob sealing, pipe materials, and system monitoring and control. Monitoring and control systems are essential for improving, verifying, balancing, and quantifying gob degasification system performance.

Gas quality, gas flow rate, and system pressure are the three characteristics of a gob gas drainage system that operators should monitor. The paper recommends that mine operators provide facilities suitable for use of hand-held measuring devices at each underground wellhead, gas moving plant, collection area, and vertical gob wellhead. Monitoring provisions (e.g., static pressure tappings, in-line orifice plates or venturi systems, and gas sampling ports) are simple, inexpensive, and easy to install and use. Operators can easily take pressure readings with manometers or diaphragm gauges and assess gas quality samples with infrared analyzers, interferometers, or acoustic methanometers. Quick, indirect gas quality measurements are also possible by measuring oxygen concentration and inferring nitrogen concentrations. The paper also discusses continuous monitoring, which is more costly and requires data transmission to a central location for analysis and system surveillance. However, for large-scale commercial operations that are concerned with gas quality, such a system can prove to be an asset.

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