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The Application of Directional Drilling Technology For Gob Gas Drainage

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Directional drilling technology has been applied in numerous gassy underground coal mines world-wide to develop horizontal, angled, or parabolic boreholes in the strata above (or under) the mining horizon for gob gas recovery. The technique applies state-of-the-art, in-mine directional drilling equipment normally used to develop long in-seam methane drainage or exploration boreholes. The technique has been applied successfully in longwall mines in Japan, China, Germany, and in the U.S. In most cases the technique is advantageous over conventional cross-measure and other superjacent (gallery) gob gas drainage methods which are more costly to apply and operate.

This paper presents the results of recent applications of this technique at several longwall mines world-wide, and outlines factors which drainage engineers should consider when evaluating the application and benefits of this technique. These factors include, placement of the boreholes in the vertical plane, completion of the boreholes, anticipated gas production and methane drainage effectiveness, and wellhead configuration and control.

Gob Degasification Techniques
There are three primary methods of longwall gob degasification techniques used world-wide, and mine operators often adopt variations of these: *surface drilled gob wells, cross-measure boreholes, and superjacent techniques (boreholes drilled from overlying galleries, and overlying or underlying horizontal gob boreholes):* Figure 1 illustrates these practices.

<u>Surface drilled gob wells</u>, most predominantly used in the U.S., are drilled in advance of mining to diameters of up to 300 mm and placed vertically, at an angle, or horizontally above the coal seam. Surface drilled gob wells are typically cased and cemented to a point just above the uppermost coal seam or gas bearing strata believed capable of liberating gas resulting from the longwall mining operation. The lower portion of the well is completed with suspended slotted casing. At some mining operations in the U.S., where overlying gas bearing strata of high gas content are present and where gob permeabilities are very high, operators can obtain excellent gas production rates and maintain high gas qualities with surface drilled gob wells operated under vacuum. Surface drilled gob wells are not suitable for mines developed under urban areas and where surface access and right-of-way are limited. Surface drilled gob wells are also difficult to implement with multiple seam operations.

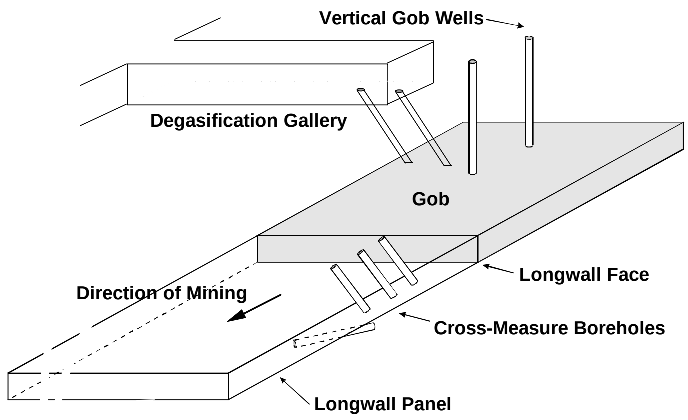

Figure 1: General Description of Gob Gas Recovery Methods

The cross-measure technique of longwall gob degasification is the dominant method used in Europe (east and west) and in the C.I.S. where longwall methods are used to mine deep multiple coal seams. Cross-measure boreholes are small diameter boreholes (75 to 100 mm in diameter) that are drilled at angles from gateroad entries up into overlying or down into underlying strata, in advance of the longwall face. In extremely gassy conditions, operators will place boreholes from the intake entry as well as the return entry, and surround the panel. The cross-measure borehole system is particularly applicable where deep reserves are mined at multiple levels and where surface access or topography limits surface options (surface drilled gob wells).

Superjacent techniques involving the use of drainage galleries developed in advance of mining in overlying or underlying strata are used at some of the deeper and gassier mining operations in Eastern Europe, the C.I.S., and China. Small diameter, short boreholes, are drilled into overlying strata from the galleries, and/or the galleries are sealed and connected directly to a gas collection system operating under high vacuum. More recently, superjacent techniques involving in-mine directionally drilled boreholes placed over or under the mining seam in advance of longwall operations have been applied In Japan, China, Australia, Germany, and in the U.S. Recent work to optimize placement, performance, and integrity of these holes has lead to the development of larger diameter holes, installation of perforated steel casing, and high angle borehole profiles. Gob degasification with superjacent techniques is applicable in mines that cannot implement surface drilled gob wells, or effectively control gob gas emissions using only these wells, and as an cost effective alternative (implementation and operation) to cross-measure boreholes.

In-Mine Directionally Drilled Gob Boreholes

This technique applies state-of-the-art, in-mine directional drilling equipment normally used to develop long in-seam methane drainage or exploration boreholes. In-mine gob boreholes, 75 to 150 mm in diameter, are drilled into the strata overlying or underlying un-mined panels to lengths up to 1,000 m. Overlying boreholes are strategically placed: (a) into (pre-mining drainage) or below the lowest producing source seam, (b) to intersect the fracture zone above the rubble zone after the gob forms, (c) over the tension zones near the edges of the panel, (d) over the low pressure or high elevation side of the gob, and (e) to remain intact following undermining and produce gob gas over the entire length of the borehole.

The advantages of this technique over the cross-measure method are: (1) the boreholes can be developed in advance of mining, away from mining activity for either advancing or retreating longwall systems, (2) fewer, longer boreholes can produce an effective low pressure zone over the gob, (3) strategic placement may allow borehole collars to remain intact (protected from the effects of local stress redistribution) and allow boreholes to remain productive after longwall mining is completed, and (4) the system may be more effective and less costly to implement and easier to operate than a system of cross-measure boreholes. Relative to a system employing galleries, horizontal gob boreholes will be less costly to implement, particularly if the galleries are developed specifically for degasification and mined in rock or uneconomic coal seams.

Case Studies

Taiheiyo Mine, Hokkaido, Japan, 1980's: Horizontal overlying gob boreholes were first implemented at the Taiheiyo Mine in Japan. These boreholes were drilled to 700 m in length at varying diameter (125 mm to 75 mm) depending on depth of hole.

Studies at this mining operation indicate that the horizontal gob boreholes were twice as efficient (methane drained / total methane liberated), and provided a 40 percent reduction in implementation cost relative to a comparable cross-measure system.

Cambria 33 Mine, Pennsylvania, USA, 1992: Nine in-mine directionally drilled gob boreholes were developed generally horizontally over two longwall panels at the Cambria 33 coal mine, which exploited the Lower Kittanning coalbed in the Northern Appalachian Coal Basin. Over 5,000 m of borehole was drilled, with the longest individual length exceeding 700 m. Borehole diameters were 88 mm. Figure 2 presents plan and profiles of the boreholes over the outline of the longwall panels. The boreholes targeted the tension zones at the ends of the panels and over the return entries to take advantage of the low pressure influence of the mine ventilation system on gob gas migration.

Various vertical horizons were targeted to assess borehole performance. In order to overcome difficulties with water accumulation in low borehole elevation areas and minimize separation requirements at the wellhead, the boreholes were steered at a consistent downgrade once they passed the desired horizontal target (performed for second panel).

Because this study was experimental in nature, the Mine also installed cross-measure boreholes (along the headgate of one of the panels) in addition to vertical gob wells. The Mine encountered problems with water accumulation and gob permeability (tight packing) which limited gob gas production from the vertical gob wells. The application of three different gob degasification techniques enabled the mine (and the U.S. Bureau of Mines) to assess the relative performance of the different systems. For example, the Mine shut-in the vertical gob wells and the cross-measure system for short periods of time to assess performance of the horizontal gob boreholes.

The following are the general conclusions of this investigation:

- For the panel section with both cross-measure and horizontal gob boreholes, horizontal gob borehole production rates were five times that of the cross-measure boreholes;
- Higher production rates occurred over the tension zones alongside the tailgate entries;
- Boreholes targeted to below the lowest contributing source seam, 24 m above the mining level recovered methane at greater rates and at higher concentrations, and remained intact in the fracture zone when undermined;
- Vertical gob well shut-in tests indicated that the horizontal boreholes were as effective as the combined system (vertical gob wells and cross-measure boreholes) at reducing gob gas emissions into the tailgate return airway;
- Boreholes produced on average of 10,000 m^3 of gob gas per day, depending on length.

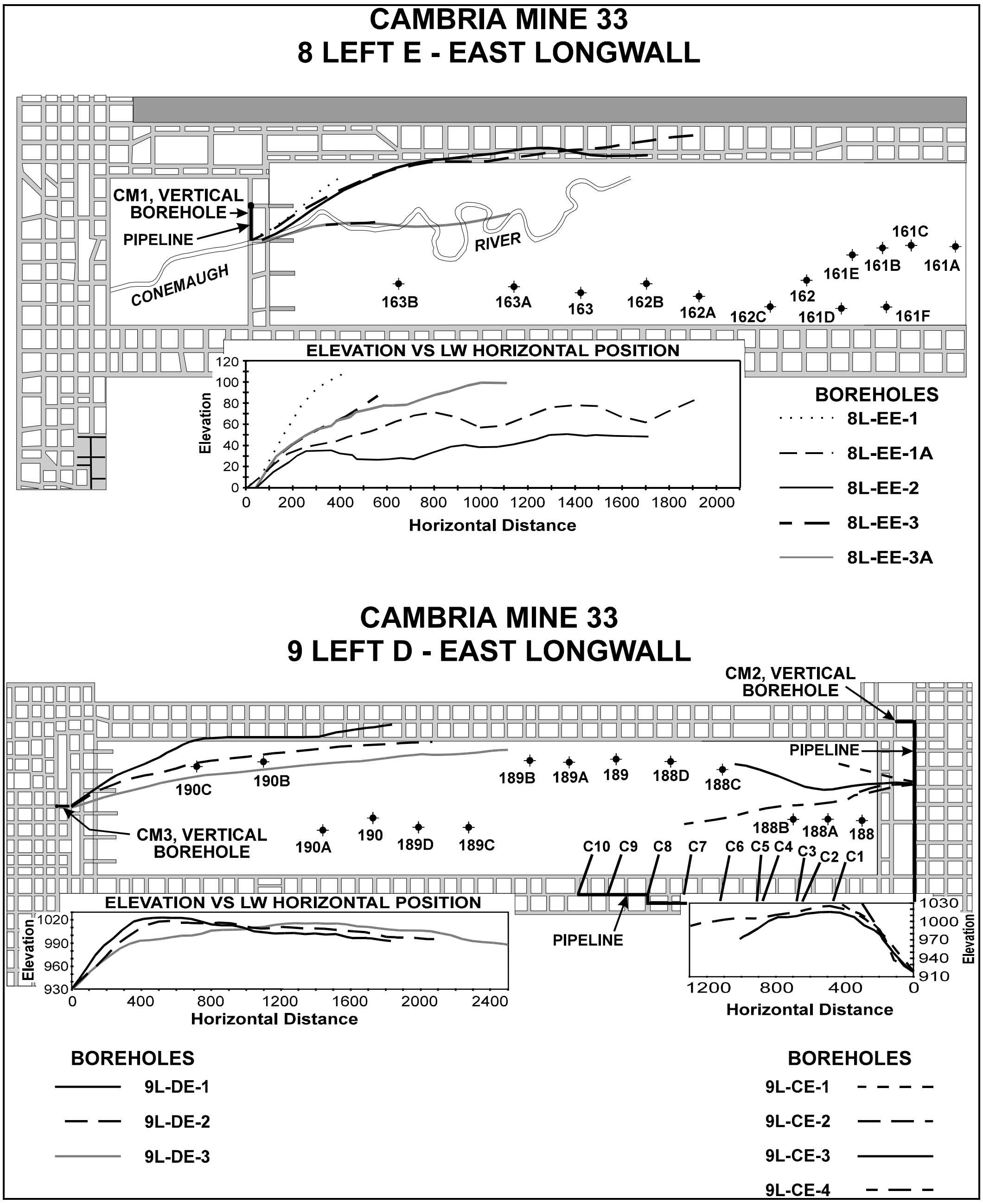

Figure 2: Plan View of Horizontal Gob Wells Developed at the Cambria 33 Mine

Daxing Mine, Tiefa Coal Mining Administration, China, 1996: Directionally drilled horizontal gob boreholes were implemented at the Daxing Mine at the Tiefa Mining Association through a Global Environmental Fund technology transfer program. Three boreholes, 90 mm in diameter, were developed from the end of the panel, extending between 150 and 300 m over the tailgate side. The boreholes were drilled to target an elevation between 35 and 45 m above the mined seam; just below the lowest gas bearing seam, coal seam No. 4. Production from the directionally drilled gob boreholes was compared with a cross-measure program applied to the same longwall panel. This investigation indicated that:

- The directionally drilled gob boreholes produced an average of 8,300 m^3 of gob gas per day;

- Gob gas quality varied between 35 to 90 percent while operation under 100 mm Hg of vacuum;

- The drainage efficiency of the directionally drilled horizontal gob boreholes is between 1.5 to 2 times that of the cross-measure borehole systems;

- The horizontal gob borehole system is less costly to implement and operate than a system of cross-measure boreholes.

Warndt/Luisenthal Mine, Saarland, Germany, 1997: Based on the in-mine gob borehole development performed by Resource Enterprises at the Cambria 33 Mine, Saarberg's research and development group funded a program to test a large diameter horizontal gob borehole and compare its performance to conventional cross-measure systems. A raise bore drill rig with high thrust capacity, 1000 kN thrust and 500 kN pull, was customized to directionally drill a 170 mm diameter borehole in excess of 500 m in length. The test borehole was directionally drilled towards the advancing longwall face, generally parallel to the mining seam and placed between 20 and 30 m above the floor of the mined seam. The length of the borehole directly over the longwall panel was lined with perforated steel casing, 137 mm diameter. This test concluded the following:

- The directionally drilled gob borehole produced on average, 13,000 m^3 of gob gas per day at 70 to 80 percent methane in air;

- Gob gas production from the horizontal gob borehole continued following longwall mining for a 25 month period at an average rate of 10,000 m^3 per day at 40 to 50 percent methane in air, indicating that the borehole remained intact over the gob;

- One 1000 m large diameter directionally drilled gob borehole would off-set over 30 cross-measure boreholes and recover gas at higher quality;

- The system enables continued gas production subsequent to mining which is generally not feasible with conventional cross-measure boreholes.

Willow Creek Mine, Utah, USA, 2000: In-mine directionally drilled gob boreholes were developed from headgate entries over two longwall panels at the gassy Willow Creek Mine (liberation of over 500,000 m^3 of methane per day) in Utah, USA. Six (6) boreholes, 100 mm in diameter, between 600 and 800 m in length were developed from headgate entries and directionally drilled to targets between 18 and 46 m above the mining seam. One borehole was drilled below the mining seam into a lower parting for floor gas control. The in-mine horizontal gob boreholes were developed to compliment and reduce the number of large diameter surface drilled angled gob wells. Resource Enterprises worked with the Mine to operate and determine optimal placement of the in-mine gob boreholes by monitoring recovered gas quality and gob gas production as a function of mining. The following is a summary of findings:

- The directionally drilled horizontal gob boreholes in the roof produced as much as 15,000 m^3 of gob gas per day (adjusted to standard conditions), at high gob gas density (1.05 m^3/kg) due to the presence of CO_2 (> 20%), and under 90 mm Hg of vacuum;

- The quality of the gob gas recovered from the boreholes was directly affected by longwall face advance rates, requiring constant monitoring and vacuum control;

- Boreholes targeted below 30 m were in direct contact with the longwall face and likely did not remain intact over the gob.

Applying In-Mine Directionally Drilled Gob Boreholes to Longwall Mines
The application of directionally drilled boreholes to control gob gas emissions from longwall panels should consider the following parameters.

Longwall panel gob gas emissions to determine the required number of boreholes required per panel. Long boreholes, in excess of 500 m, at 100 mm in diameter will recover approximately 15,000 m^3 of gob gas per day under high vacuum (100 mm Hg). Larger diameter directionally drilled holes, 150 mm in diameter, for example, have the capacity to recover over 3 times this flow rate for holes between 300 and 500 m in length.

Source of gob gas emissions. Boreholes should be directionally drilled below the lowest producing overlying source seam as possible, but in the fracture zone which is under tension above the gob. Floor boreholes must consider water accumulation and be drilled up-grade if possible, and placed above the nearest contributing seam

Geomechanical characteristics of the overlying strata, in particular, to project the vertical and lateral extent of the rubble zone, and aid in vertical and horizontal placement of the boreholes. The rubble zone typically extends to 5 times the mining height, and the fracture zone, over 35 times the mining height, depending on the geomechanical conditions, the mining plan, and depth to surface. Where efficient caving occurs, the lateral extent of the rubble zone extends close to side pillar abutments and directly behind the longwall shields.

Optimal vertical placement of the boreholes. This is typically determined by trial and error and will require more than one panel to optimize. Optimization of vertical placement requires varying the elevation of the boreholes along their length and properly monitoring gas flows, gob gas qualities, longwall face production, and controlling vacuum at the wellheads. Properly placed boreholes remain intact over the gob and are effective over their entire length, producing higher quality gas.

Placement of boreholes to reduce gas content in advance of mining and minimize gob gas emissions. Where possible, particularly with higher permeability surrounding coal seams, directionally drilled gob boreholes can serve dual purposes: reduce in-situ gas contents in advance of mining, and recover gob gas during mining.

Borehole lining improves the viability of overlying gob boreholes. Larger diameter directionally drilled boreholes are required to accommodate the perforated steel casing. These boreholes remain intact even when placed too low over the mined panel, and provide protection from air intrusion near the borehole collar. With proper lining (perforated and solid) directionally drilled gob boreholes can produce for long periods of time subsequent to mining.

Pressure distribution in the gob. Gob gas will accumulate toward the low pressure side of the gob (tailgate side, or along the ventilation return), and higher elevations.

Target strata tension zones at the start and ends of longwall panels. Geomechancical characteristics and mining plans, advance rate, and depth, determine the extent of these zones in the vertical and horizontal plane. Where efficient caving occurs, tension zones are narrower laterally along the longwall panels.

Water accumulation in the boreholes. To produce free gas or desorb gas from overlying strata in advance of mining, the boreholes should be directionally drilled up-grade to allow water drainage and separation at the wellhead. Down-grade boreholes should be equipped with a de-watering system (air or gas lift) to enhance production of free gas and gob gas. Where significant water is encountered and only gob gas production is desired, a parabolic or down-grade hole is preferred. Water accumulated in the borehole drains towards the end of the hole into the gob through fractures created by under-mining.

Drilling locations are often dictated by outby mining activities. Proposed locations must consider the gas collection route, typically return air course, the size of gob gas collection pipelines and equipment (large diameter due to vacuum), the timing of development workings, the limitations of equipment and drilling conditions (dictates borehole diameter and length), access for mine equipment, hauling, belts, etc., and the stability of the area for borehole collar protection.

Monitoring and control requirements, particularly during initial deployment. The initial boreholes should be connected to a pipeline system under vacuum. Each borehole collar should provide for monitoring of vacuum pressure, gas flow rate, and gas quality. The vacuum system should provide flexibility in capacity and pressure by (1) providing gas recirculation capabilities at the pumps, and (2) drawing gas from other sources to provide more consistent operation such as gas from sealed areas.

Monitor methane quality indirectly. Infra-red and other monitors are affected by the presence of moisture or higher hydrocarbons in the gob gas. Effective monitoring of methane concentration can be accomplished at low cost by monitoring oxygen levels in the gas stream. Methane concentrations are determined indirectly by less frequent but routine gas chromatograph sampling.

Alternative Borehole Configurations Applied by Resource Enterprises

Alternative directional drilling techniques applied by Resource Enterprises include large diameter directional borehole drilling for high capacity gob gas recovery in very gassy conditions, and the development of parabolic boreholes to simulate effective surface drilled angled gob wells.

Large diameter directionally drilled boreholes in the roof and lined with perforated steel casing can serve as collector boreholes for tangential directionally drilled horizontal boreholes drilled parallel to longwall panels as shown on Figure 3. This concept specifies a 150 mm collector borehole lined with 100 mm perforated steel casing, and 100 mm unlined tangential boreholes. The flow capacity of the system is estimated at 20,000 m^3 per day at 70 percent methane in air and a wellhead vacuum of 100 mm Hg.

Large diameter parabolic boreholes lined with perforated steel casing can compete with very effective surface drilled angled or vertical gob wells. These boreholes can be drilled from the mining level to an apex above the highest contributing overlying source of gas and descend gradually through the gob gas sources as shown on Figure 4. Large diameter, 200 mm angled surface drilled gob wells can produce up to 80,000 m^3 of gob gas per day at high vacuum; 200 mm Hg.

Conclusions

In-mine directional drilling techniques provide mine operators an alternative approach to gob degasification. In many cases directionally drilled in-mine gob boreholes can displace conventional techniques and provide a lower overall cost approach. The application of this technique to implement overlying gob boreholes requires careful consideration as borehole placement, including collar location, can significantly affect producibility. The ability to increase diameter and line these boreholes with solid and perforated steel casing improves their use for post-mining gas recovery, and improves the success of the technique. Alternative in-mine gob borehole configurations such as the parabolic concept avoid the vertical placement issue of horizontal boreholes and can simulate highly effective angled or vertical gob wells drilled from surface.

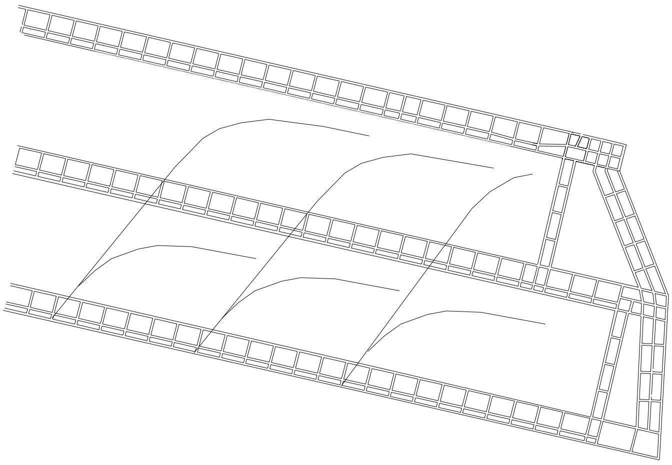

Figure 3: System of Large Diameter Collection Boreholes with Tangential Angled or Horizontal Gob Boreholes.

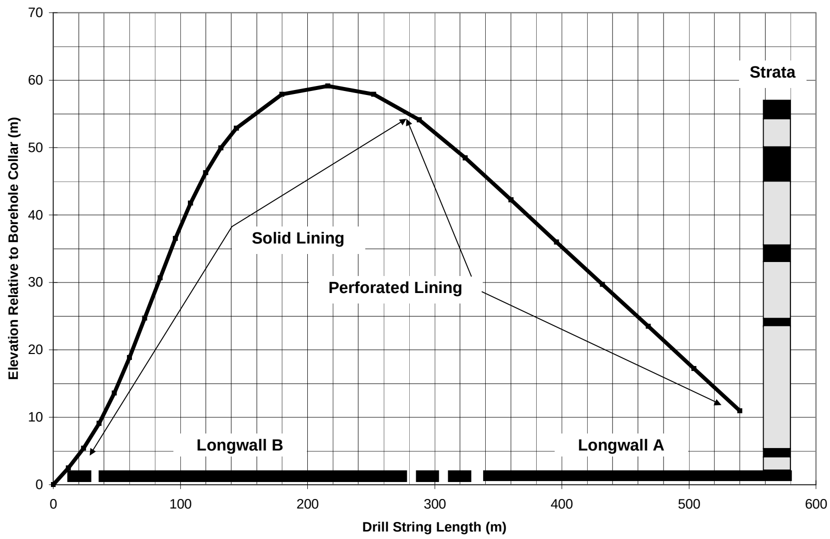

Figure 4: High Angle Parabolic Boreholes

References

Ohga, K. and Higuchi, 1987, “The Practice of Methane Drainage in Japan:, 3rd U.S. Mine Ventilation Symposium, Pennsylvania State University, Pennsylvania, U.S.

Schloenbach, M., Hert, H., Steffens, R., 1997, “Directional Drilling Technology at Saarbergweke AG”, Ertzmetall, Vol. 50, No. 2, pp. 129-136.

Schwoebel, J. and Chiari, D., 1993, “Utilization of Horizontal In-Mine Gob Ventilation Boreholes at the Cambria Slope No. 33 Mine”, International Coalbed Methane Symposium, Tuscaloosa, Alabama, U.S.

Yang Shi’an, Wen Yongyan, Sun Yuyin, Cao Shiying, Fu Qingwu, and Liu Hongwei, 1998, “Gob Gas Drainage with Directional Long Horizontal Roof Boreholes”, Proceedings of the International Workshop on Coalbed Methane Recovery and Utilization, China Coalbed Methane, Serial No. 4.