Modern CMM drainage strategies

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ABSTRACT: Numerous advances have been made in directional drilling equipment over the last five years. This paper will review specific improvements in this technology and present how this impacts CMM drainage strategies for underground coal mines. Long in-seam boreholes can be placed in the working seam far in advance of mining to significantly reduce in-situ gas contents of virgin reserves and commercially recover CMM. Directionally drilled boreholes can also be drilled into overlying strata to reduce the in-situ gas content of gas bearing strata in advance of mining (this gas would otherwise contribute to gob gas make), and subsequently recover gob gas liberated during under-mining (reduce emissions of CMM into mine workings). Precision placement, ultra-long boreholes, and higher capacity boreholes enable mine operators to more effectively recover the "total resource" (coal and CMM), reduce CMM emissions during mining, and improve mine safety.

1 INTRODUCTION

REI Drilling, Inc. ("REI") is a wholly and employee owned subsidiary of Resource Enterprises, Inc., formed in the early eighties and has evolved into an internationally recognized directional drilling services company. REI operates seven drills domestically that provide directional drilling solutions to the coal mining industry for CMM drainage, geologic and old works exploration, water drainage and transfer, and de-stressing. CMM drainage solutions include the application of long directionally drilled boreholes that: (1) immediately reduce CMM emissions into mine developments; (2) are placed significantly in advance of mining and reduce gas contents of large virgin areas, and; (3) serve dual purposes; reduce the gob gas potential of overlying source seams and subsequently recover gob gas liberated during undermining. These solutions are implemented globally through contract drilling services and technology transfer, including in the United Kingdom and the Ukraine slated for 2006.

Recent (last 5 years) developments in directional drilling technology that are considered "modern" in this paper include higher capacity underground drills, peak performing water pumps, higher torque down hole mud motors, rapid penetration drill bits, and precise steering tools that can be coupled with geophysical sensors.

These recent developments impact all CMM drainage strategies that involve long boreholes drilled either in advance of mining, or for gob gas recovery. These developments provide for precision placement, ultra-long depths, and drilling at larger diameters. As a result, directionally drilled boreholes can drain larger areas in advance of mining, be placed strategically as in-fill boreholes between vertical CMM wells to substantially reduce the gas content of large reserves, and recover higher volumes of gas.

2 MODERN DIRECTIONAL DRILLING TECHNOLOGY

2.1 *High Capacity Drills*

Since 2000, underground directional drills have been built with increased axial thrust and pull-back, and rotational torque capacity. For example, a current project funded by various US government entities and managed by Partnership for Energy and Environmental Reform ("PEER") will introduce modern underground directional drilling equipment to Ukraine and initiate work in 2006 at the Krasnolimanskya Mine. This drill was built by J.H. Fletcher

& Co. under REI oversight and designed with an axial thrust of 50,000 lbs and rotational torque of 2,400 ft-lbs. This is an increase from prior models designed with a thrust and pull-back force of 40,000 lbs, and a rotational torque capacity of 1,700 ft – lbs.

Additionally, these high capacity units are built with articulation capability, specifically for the application of overlying gob boreholes.

2.2 *Peak Performing Water Pumps*

The high capacity drills are equipped with higher volume reciprocating water pumps; with 33 percent more flow capacity. This additional water volume provides the ability to operate down-hole motors at higher rpm, and the flexibility to use alternative lobe configurations or larger diameter motors with higher torque.

For example, excellent penetration rates have been achieved with down-hole motors operating at 1050 rpm in very hard rock for the application of horizontal gob boreholes. The additional water can produce an increase in down-hole torque from approximately 170 ft-lbs to over 350 ft-lbs with the use of a larger diameter down-hole motor and enable larger diameter directional drilling.

2.3 *High Strength Down Hole Mud Motors*

Modern down-hole motors are built with heavy duty tungsten carbide bearing packs that provide 33 percent more wear surface. These motors are equipped with transmission shafts made of Astralloy™, which is an alloy with fatigue limits 25 percent higher than 4140 chrome alloy.

These motors provide increased operational life and the ability to develop larger diameter boreholes at longer lengths using mud-motor reaming techniques.

2.4 *Rapid Penetration Bits*

Modern directional drilling bits used for the development of long in-seam boreholes are crown shaped and fitted with large 13 mm diameter poly diamond crystalline cutters. In harder coals, for example those with a Hardgrove Grindability index of less than 40, penetration rates over 1,000 ft in a single 8 hour shift have been achieved. This is particularly advantageous when drilling in-seam boreholes that immediately reduce CMM emissions into mine workings (in higher permeability coals).

2.5 *Precise Steering Tools*

The modern down hole survey tool provides high speed data acquisition from very accurate geometric sensors (tri-axial magnetometer and accelerometers) positioned behind the mud motor, on a demand basis. Recently available steering tools developed specifically for directional drilling in underground coal mines provide the ability to integrate geophysical sensors such as focused gamma and magnetometers in with the geometric sensors. These steering tools provide real time data to the drill operator through a PC based system with graphical interpretation.

Data provided by modern steering tools is integrated into AutoCAD® software for further geologic interpretation with drilling logs, and placement of boreholes and geologic features on mine maps for the coal operator.

3 IMPACT ON CMM DRAINAGE STRATEGIES

3.1 *Precision Placement*

Modern directional drilling technology enables precise placement of long boreholes. This is critical for the successful implementation of the following CMM drainage strategies: (1) placement of horizontal gob boreholes in specific overlying strata to serve dual purposes; (2) navigation of horizontal in-fill boreholes around vertical CMM wells; (3) installation of closely spaced in-seam boreholes to uniformly reduce gas content in tight coal seams; and (4) implementation of an effective pattern of in-seam hydraulic fractures.

3.1.1 *Borehole Accuracy* Placement accuracies of less than 0.5 degrees horizontally and 0.1 degrees vertically can be achieved with modern directional drilling steering tools. Prior to drilling, these tools are calibrated to mine grid to compensate for the magnetic declination in the region and the dip of the magnetic field. Accurate placement cannot be achieved without proper calibration.

Figure 1 illustrates a mine intercept of an in-seam directionally steered borehole. The borehole was found to be 8.6 ft left of its location at 2,500 ft, as determined by borehole surveys obtained during drilling. This corresponds to a placement accuracy of less than 0.2 degrees in the horizontal plane.

3.1.2 *Dual Purpose Boreholes* From underground mining horizons, in-seam boreholes can be directionally drilled and steered through roof or floor strata and precisely placed in overlying or under-

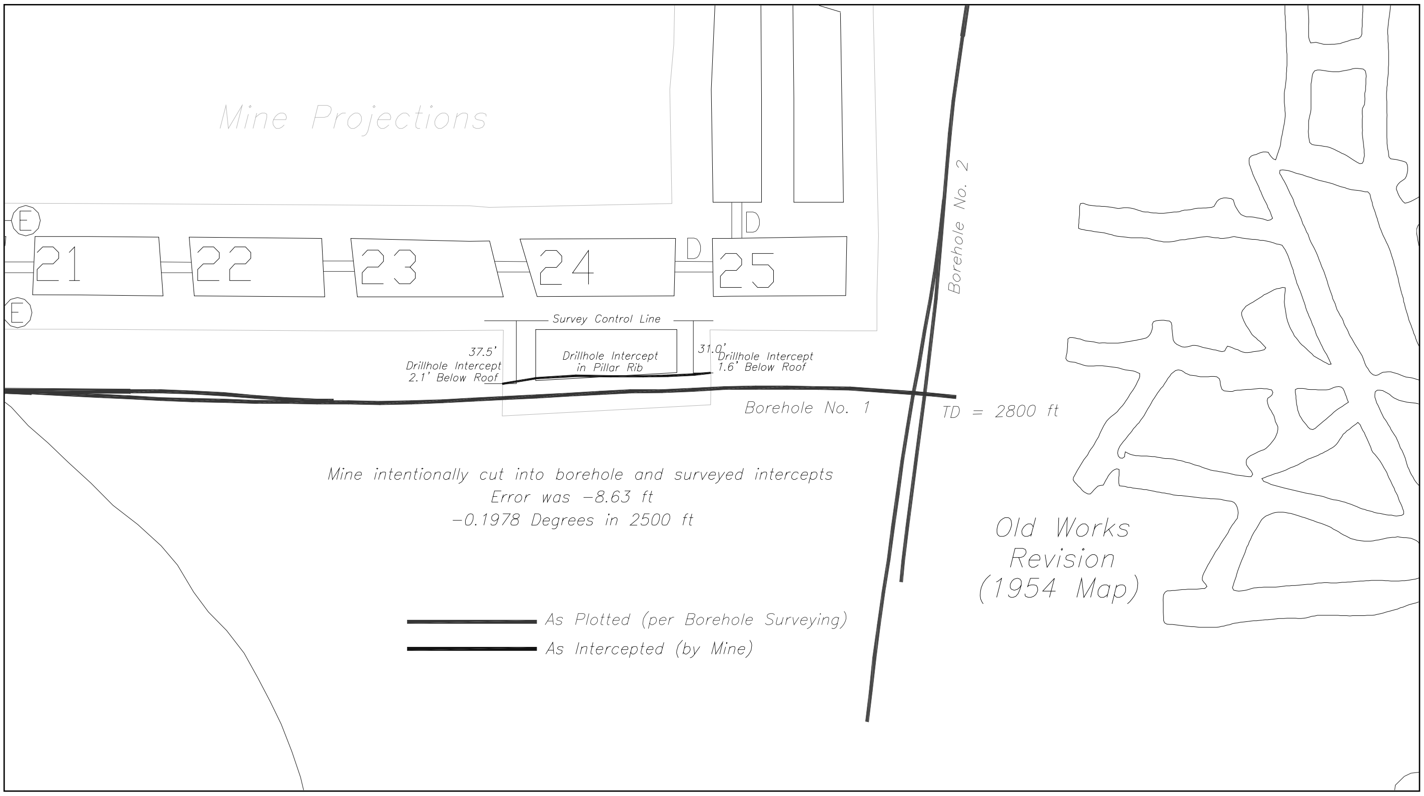

Figure 1. Mining intercept of an in-seam borehole illustrates high placement accuracy.

lying coal seams for pre-mining drainage of gas or water as well as to increase gas recovery for commercial purposes. Boreholes placed in an overlying coal seam in advance of mining can serve two purposes. If the target coal seam is gassy and contributes to gob gas when undermined, in-seam drainage in advance of undermining will reduce the gas content of this coal seam and decrease its contribution to the gob gas make when undermined. Depending on the elevation of the coal seam relative to the mined seam, the overlying boreholes can serve a secondary purpose as gob gas boreholes. Horizontal gob boreholes placed in overlying coal seams between 50 and 120 ft above the mined seam can remain intact in the fracture zone (they can also be lined). When placed adjacent to low ventilation pressure entries and in tension zones along gate roads horizontal gob boreholes will successfully control gob gas when placed under vacuum. Lastly, this borehole can provide pre-mining water drainage

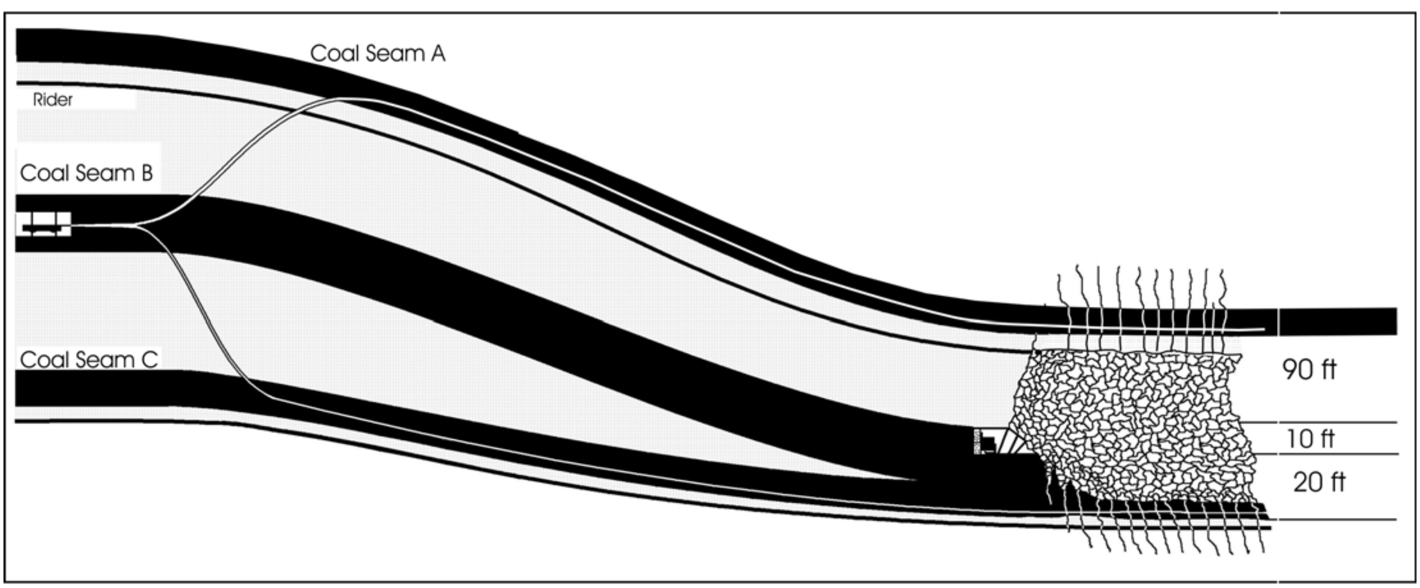

Figure 2. Dual purpose overlying borehole reduces gas contents of gob gas contributing source seam in advance of undermining and subsequently serve as gob boreholes.

of overlying strata and minimize water production after undermining. Figure 2 illustrates the dual purpose principal; reduce the gas content of the gob gas contributing source seam before it is mined, and then use the borehole to reduce gob gas emissions into workings during mining.

As the vertical elevation of contributing seams is not known precisely, this strategy typically requires identification of the seam by direct contact, and then directionally drilling a tangential borehole to precisely place the borehole so that it can be maintained in the seam.

3.1.3 *Horizontal In-Fill Boreholes* Some gassy US coal fields contain reserves that were aggressively drilled with hydraulically stimulated vertical wells. Although these operations have been successful, several mine operators have determined that the residual gas content of the coal seam could be further reduced to improve safety and the efficiency of underground coal extraction. As shown on Figure 3, long, directionally drilled in-seam boreholes can be accurately placed in-filling areas between the vertical wells to produce CMM and further reduce gas contents. Precision placement is required to successfully navigate in-seam boreholes near the vertical wells. Borehole stability problems arise near the hydraulic fractures, which can also lead to fluid circulation problems when intercepted. Although fracture orientations are generally known, the exact location and extent are not. This strategy requires precise placement to adhere to safe drilling zones, particularly at borehole lengths in excess of 5,000 ft.

3.1.4 *In-Seam Boreholes in Tight Coals* In order to reduce gas contents in advance of mining in very gassy, tight coal seams (overseas in areas where anthracite is mined, for example) in-seam drainage strategies demand very closely spaced boreholes. In some conditions, boreholes spaced between 15 ft and 50 ft are required, depending on the time available for drainage, and the in-situ gas content. Drilled along the longitudinal axis of longwall panels, or across multiple longwall panels, closely spaced in-seam boreholes need to be placed precisely to achieve the required lengths and not intersect, and to reduce gas contents uniformly.

Accurate placement of in-seam boreholes is also necessary to maximize the benefit of hydraulic stimulation of in-seam horizontal boreholes in tight, gassy coal seams. Redundant fractures and fracturing into adjacent boreholes can reduce the effectiveness of this stimulation practice.

3.2 *Longer Boreholes*

CMM drainage strategies involving longer boreholes are made possible by modern directional drilling technology. In-seam boreholes in excess of 5,500 ft in depth have been developed from under-

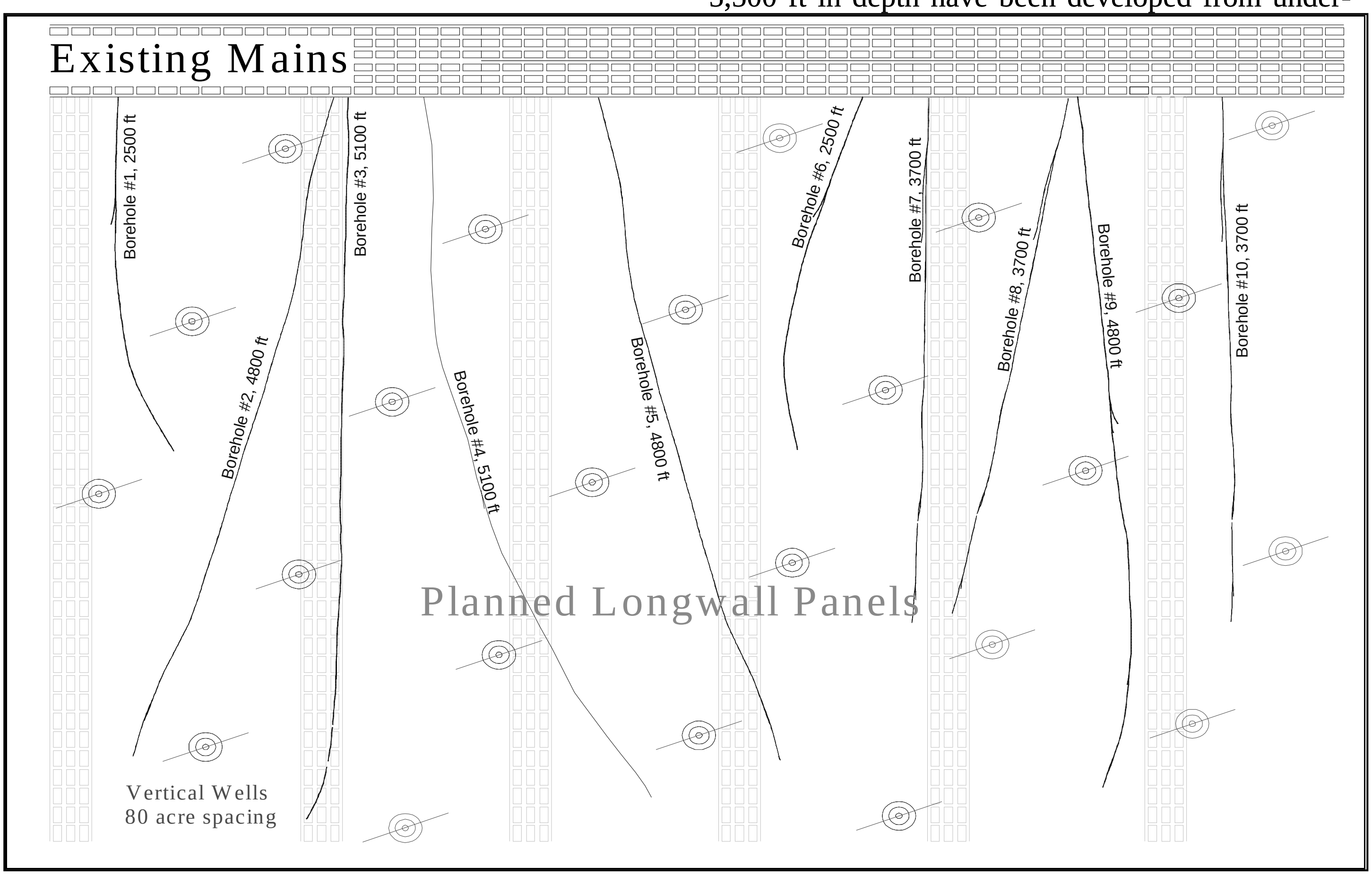

Figure 3. In fill drilling of horizontal boreholes between hydraulically stimulated vertical wells.

ground coal mines. These ultra-long boreholes provide remote access to large areas of virgin reserves and initiate CMM drainage long before actual mining to significantly reduce in-situ gas contents.

3.2.1 *Reduce Gas Contents Significantly in Advance of Mining* Longer in-seam boreholes can effectively reduce gas contents of large reserves in advance of mining. Because of their length, these boreholes can extend into areas that will not be immediately mined and typically can drain gas for longer periods of time (before intercepted by mining). Drilled orthogonally to future longwalls as shown on Figure 3, long in-seam boreholes can span as many as four (4) typical longwall panels.

Longer in-seam boreholes produce more gas as the increased surface area of the borehole intercepts more natural fractures and cleats. In gassy, high permeability coals, ultra-long in-seam boreholes can initially produce as much as 300 MSCFD of methane per foot of hole.

3.2.2 *Access Large Virgin Reserves* Longer in-seam boreholes can access large virgin tracts to produce gas commercially, and reduce in-situ gas contents to enable safer mining. CMM drainage strategies involving drilling long in-seam boreholes from mine infrastructure developed in advance, such as ventilation shafts, can at current market rates for natural gas, provide a revenue stream to more than offset the advanced development (depending on reservoir conditions). Radial in-seam boreholes developed into coals at multiple levels from a shaft can produce as much as 2 BCF, depending on reservoir conditions.

3.2.3 *Access Deeper Virgin Reserves* CMM drainage strategies involving directional drilling into dipping coal seams from surface, for example, to reduce gas contents in advance of mining, and for commercial recovery, benefit from longer boreholes. Longer boreholes can access deeper reserves under higher reservoir pressure and at higher gas contents, increasing gas production and the area drained.

3.3 *High Performance Horizontal Gob Boreholes*

Modern directional drilling technology improves the capability of horizontal gob boreholes. Horizontal gob boreholes are directionally drilled over the mining seam in advance of the longwall face and placed vertically in what will be the fracture zone when the gob forms, and typically along the lower pressure side of the gob in the horizontal plane. Various parameters affecdt the performance of the horizontal gob boreholes: (1) diameter and length, (2) vertical and horizontal placement relative to the working seam and mine ventilation system, (3) borehole integrity following undermining, and (4) borehole production issues related to vacuum and dewatering.

Horizontal gob boreholes have been applied at several mines in the U.S., and overseas in China, Japan, and Europe, with varied success. Typically a 3 inch to 4 inch diameter borehole, 1,000 ft to 2,000 ft in length, placed between 75 ft and 100 ft above the mining seam, produces between 200 and 400 MCFD of gob gas under vacuum.

Experience in the U.S. suggests that horizontal gob boreholes are not always as effective as vertical gob wells, but in some cases vertical gob wells do not work due to tight packing of gob, or are cost prohibitive. Horizontal gob boreholes, should be given consideration in areas of deep cover, restrictive surface areas and multiple seam mining. In these particular cases, horizontal gob boreholes are likely to be safer, more cost effective and efficient than traditional systems. In many cases, horizontal gob boreholes significantly improve CMM drainage efficiencies at mining operations overseas that employ cross-measure boreholes.

3.3.1 *Higher Capacity Boreholes* Modern directional drilling technology allows for development of longer horizontal gob boreholes at larger diameters. Both of these parameters affect the resistance of the borehole to gob gas flow. Using actual gob gas composition, vacuum pressure and flow data from horizontal gob boreholes employed at the Willow Creek Mine in Utah, correlation exercises determined that the Mueller equation for gas flow best represented measured conditions. This relationship was used to derive flow capacities of varying borehole diameter configurations achievable with modern directional drilling technology. Figure 4 illustrates the incremental increase in flow capacity at a vacuum of 6 inches Hg for a 3,280 ft horizontal gob borehole drilled at 3.8 inches in diameter (standard), relative to the flow capacity of a borehole partially and completely reamed to 5.75 inches in diameter using modern directional drilling techniques. The corresponding predicted gob gas flows increase from 300 MSCFD to 950 MSCFD.

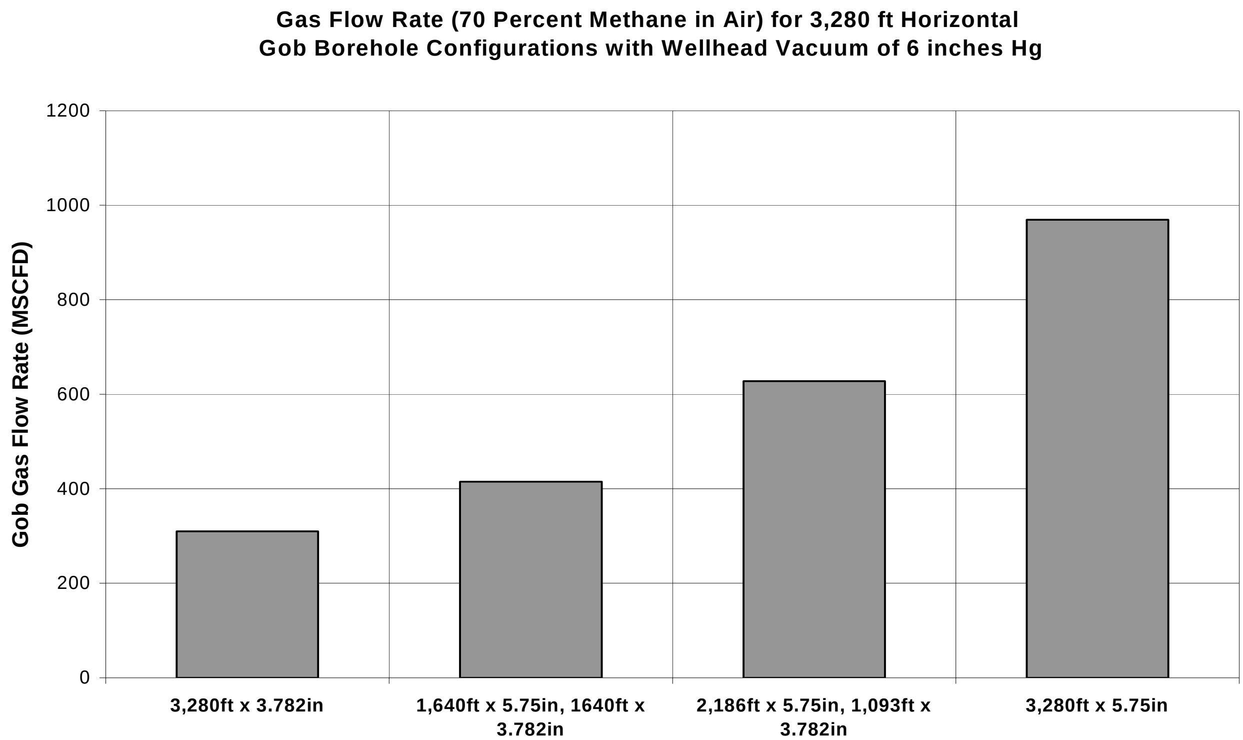

Figure 4. Gob gas flow capacity as a fucntion of borehole diameter and length for a given wellhead vacuum pressure.

3.3.2 *Maintaining Integrity when Undermined* Horizontal gob boreholes are typically directionally drilled to rapidly gain elevation above the working seam and steered to be placed between 75 to 125 ft above the top of and oriented parallel to the mined seam. The exact orientation is dependent on the location of gas contributing strata and geo-mechanical characteristics of the gob. If placed too low and near the rubble zone, the horizontal gob boreholes may not maintain their integrity when undermined, and/or may draw significant volumes of ventilation air above the face, diluting recovered gas concentrations. Horizontal gob boreholes placed too high intercept fractures that are less conductive and may not be as effective as boreholes placed at optimal horizons.

Modern directional drilling technology enables the development of larger diameter horizontal gob boreholes that can be lined with perforated steel so that integrity is maintained irrespective of vertical placement. A smaller diameter pilot borehole is directionally drilled and then reamed using conventional or mud-motor reaming techniques, depending on depth. Lining ensures that all holes will remain intact and will produce gob gas even if placed too low in the gob.

3.3.3 *Operating Horizontal Gob Boreholes* Because of their placement in the gob, horizontal gob borehole performance depends on longwall face activity and wellhead vacuum. Ideally, operators should control vacuum based on face conditions. During longwall mining, increasing the wellhead vacuum pressure will result in increased gas production. Unfortunately high vacuum pressures during face idle periods will draw excessive ventilation air and reduce recovered gob gas concentrations.

4 CONCLUSION

Developments in directional drilling technology over the last 5 years improve on CMM drainage strategies that involve long steered boreholes. Stronger, more powerful equipment, coupled with real-time precision down-hole navigation allow for longer, more accurately placed boreholes at larger diameters. Accurate placement provides the ability to safely install in-fill boreholes among hydraulically stimulated vertical wells, install dual purpose boreholes in overlying or underlying seams, and implement enhanced CMM drainage techniques in tight coals. Longer in-seam boreholes target larger reserves and allow commercial recovery of CMM while reducing gas contents for safe and more productive mining in the future.

There is growing interest in larger diameter horizontal gob boreholes as a viable alternative in certain areas to vertical gob wells and conventional cross-measure boreholes. Various case studies allowed a better understanding of the technique and have demonstrated significant gob gas productivity. Advancements in directional drilling equipment allow larger diameters to be drilled for installation of slotted and conventional steel liners so that borehole integrity and gas production is maintained after undermining.