State-of-the-Art in Coalbed Methane Drilling Fluids

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Summary

The production of methane from wet coalbeds is often associated with the production of significant amounts of water. While producing water is necessary to desorb the methane from the coal, the damage from the drilling fluids used is difficult to assess, because the gas production follows weeks to months after the well is drilled. Commonly asked questions include the following:

- What are the important parameters for drilling an organic reservoir rock that is both the source and the trap for the methane?
- Has the drilling fluid affected the gas production?
- Are the cleats plugged?
- Does the "filtercake" have an impact on the flow of water and gas?
- Are stimulation techniques compatible with the drilling fluids used?

This paper describes the development of a unique drilling fluid to drill coalbed methane wells with a special emphasis on horizontal applications. The fluid design incorporates products to match the delicate surface chemistry on the coal, a matting system to provide both borehole stability and minimize fluid losses to the cleats, and a breaker method of removing the matting system once drilling is completed.

This paper also discusses how coal geology impacts drilling planning, drilling practices, the choice of drilling fluid, and completion/stimulation techniques for Upper Cretaceous Mannville-type coals drilled within the Western Canadian Sedimentary Basin. A focus on horizontal coalbed methane (CBM) wells is presented.

Field results from three horizontal wells are discussed, two of which were drilled with the new drilling fluid system. The wells demonstrated exceptional stability in coal for lengths to 1000 m, controlled drilling rates and ease of running slotted liners. Methods for, and results of, placing the breaker in the horizontal wells are covered in depth.

Introduction

Methane production from coal has become one of the more interesting practices in recent years to produce hydrocarbons (MacLeod et al. 2000; Peters 2000; Hower et al. 2003; Stevens and Hadiyanto 2004; Mavor et al. 2004; and Bastian et al. 2005). In the United States in 2005, it is estimated that 11.7% of all gas produced is from CBM sources (Mohaghegh et al. 2005).

While in conventional drilling in sandstones and carbonates, it is often simple to tell if a drilling fluid is fully or partially responsible for formation impairment, it is often much more difficult see in CBM wells. When a CBM well depends on the production of water to reduce formation pressure and thus lead to gas desorption, the influence of drilling fluid becomes masked or even forgotten.

As the frontiers of CBM wells are pushed into the horizontal drilling realm, the importance of the drilling fluid is magnified. The fluid needs to both stabilize the wellbore during the drilling phase, but at the same time minimize any production shortfalls caused by damage. A simple N_2 fracture, which may be used on a 5 to 10 meter (m) vertical coal seam, is not a simple matter to transfer to a 500 to 1000 m horizontally drilled coal section.

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Basic Coal Geology

If you were to hand a piece of coal to someone you knew and asked them to describe it, they would probably say "it's black." In fact, they are right, but there is more to coal than what meets the eye, especially if you do not know what you are looking for. Coal is a very complicated organic rock made up of tiny microscopic constituents called "macerals" that are analogous to the minerals found in inorganic rocks, such as quartz. Macerals are made up of various lithified plant debris, such as spores, pollens, waxes, cuticles, and resins. There are three main groups in which macerals are classified—the vitrinite group, inertinite group, and liptinite group—all which can be broken down further into several individual macerals. Macerals of similar character can be grouped into "microlithotypes," microscopically discernible units analogous to laminations in sedimentary rocks, such as sandstones. Microlithotypes are further combined to form macroscopically visible units called "lithotypes," which are analogous to beds in other sedimentary rocks and classified on the basis of their brightness. For example, a lithotype predominantly made up of the vitrinite group looks very bright. In contrast, coal rich in inertinite looks very dull. The dull and bright bands indicate something about the heterogeneity of the coal and how variable its physical make up is both vertically and laterally. Each lithotype comes with its own set of physical properties that can enhance or impede production of coalbed methane.

Coal rank is another important physical property and is a measure of the degree of chemical alteration (also referred to as "diagenesis") undergone by the coal. The longer the coalification process continues, the higher rank the coal becomes. Vitrinite content also changes with coal rank, as do several other physical properties important to CBM potential (Smith et al. 1994) **(Table 1).**

Cleating. Permeability is the single, most important physical characteristic of any coal relative to CBM production. Permeability in coal is a direct function of the cleat and/or fracture network present. As coal matures through the process of coalification, moisture and volatile gasses are slowly driven off resulting in the shrinking of the coal matrix. As the coal "shrinks," cleats begin to form, similar to the cracks that develop when mud dries under the heat of the sun. The cleat/fracture system in coal is also referred to as the macropore system.

A good metaphor for visualization is a loaf of sliced bread **(Fig. 1).** The spaces between the slices of coal are fractures referred to as "face cleats." The spaces within the slices of coal are referred to as "butt cleats," which may, or may not, intersect with the face cleats. When we refer to coal "permeability," we actually refer to the permeability obtained from the fractures network. Face cleats are very important, because they are the backbone of coal permeability. Butt cleats may contribute to such permeability if they intersect the face cleat network. A third set of fractures can be found on coals that have been exposed to tectonic stresses. These third sets of fractures are referred to as "tectonic fractures" and are very important to CBM production. Tectonic fractures increase the permeability of the coal by two mechanisms: (a) their own presence and (b) by connecting to some of the butt cleats previously not part of the fracture network. With the great heterogeneity

TABLE 1—COAL RANKING CLASSIFICATION BY VITRINITE REFLECTANCE, VOLATILE MATTER, BED MOISTURE, AND CALORIC VALUE (SMITH ET AL. 1994)

Coal Rank		Vitrinite Reflectance (random)	Volatile Matter (wt% ddmf)*	Bed Moisture (wt%)	Calorific Value (MJ/kg)**
Class	Rank				
Anthracite†	Meta		< 2		
	Anthracite	> 2.50	< 8		
	Semi	> 1.92	< 14		
Bituminous	Low volatile	> 1.51	< 22		
	Medium volatile	> 1.12	< 31		
	High volatile A	> 0.75			> 32.6
	High volatile B	> 0.50–0.75			> 30.2
	High volatile C			< 8–10	> 26.8
Subbituminous	A	> 0.50 ?			> 24.4
	B			< 25	> 22.1
	C	> 0.42		< 35	> 19.3
Lignite	A				
	B			< 75	> 14.7
	Peat				

* ddmf is dry mineral matter free
** MJ/kg is Megajoule/kilogram
† If agglomerating, classified as High Volatile C Bituminous

within a single coal network, the range of fractures presence can vary from no fractures to complete three-set fracture development.

Maceral type and coal rank are the two most important controlling factors in cleat development. For example, a vitrinite rich high-ranking coal has excellent potential for cleat development. In contrast, an inertinite rich, low-ranking coal has very little potential for cleat development. As previously discussed, coals can be very heterogeneous with several lithotypes over a very small vertical distance (centimeters [cm] to m). If you had two lithotypes vertically adjacent to one another, one rich in vitrinite and the other rich in inertinite, the vitrinite-rich layer, or lithotype, would show better cleating even though the entire coal is of equal rank (CSPG, CSEG, and CWLS 2006) **(Fig. 2).**

Depth is an important factor to consider when talking about cleats and their apertures. Generally speaking, the effective permeability of coal decreases with burial caused by compaction.

Storage and Desorption. Methane can be stored in two places within coal; in either the cleats/fractures or macropore structure; and in the matrix or micropore structure. The macropore system is when the effective permeability is measured and are shown to be the conduits in which the methane travels into the wellbore. The cleats/fractures are filled with methane molecules, which have attached or adsorbed on the surface of the coal; this is known as "free" gas **(Fig. 3).** In the micropore system, there is significantly less permeability. Imagine a sponge with millions of tiny cavities, but none of the cavities connected to one another. The majority of the methane gas is stored (i.e., adsorbed) in either these micropores or matrix porosity, and referred to as "bound" or "trapped" methane.

Desorption, the opposite of adsorption, occurs when a methane molecule detaches from the cleat face and starts to flow toward an area of lower pressure—in this case, the wellbore. As desorption continues to take place, the methane adsorbed onto the cleat face or free gas begins to dissipate. When there is no more free gas to be desorbed, the bound or trapped gas starts to make its way into the cleat network by the process of diffusion (King et al. 1986). Once the bound methane molecules reach the cleat face, migration to the well bore is accelerated because of the greater permeability of the cleat network.

Coal vs. Noncoal Reservoirs. The main characteristic that distinguishes coal bed reservoirs from conventional reservoirs (i.e., sandstones and carbonates) is the source of the hydrocarbons found in them. In conventional reservoirs, the hydrocarbons, are generated in source rocks found elsewhere in the stratigraphic section. Over time, these hydrocarbons migrate into these porous reservoirs and become trapped. Coal bed reservoirs can also become "charged" with hydrocarbons by way of migration from organic-rich source rocks but, the difference is that coal can typically generate its own hydrocarbon from within. No outside source is necessary, because coal itself is an organic-rich source rock.

A second difference is that the surface of the coal is more chemically charged than the surface of conventional sandstone or carbonate rocks. What is even more intriguing is the fact that its charge has the tendency to change with the change of the pH in its environment. As subsequently seen in this paper, the surface charge plays an important role in drilling, formation damage, and production.

Rock Mechanics

Unlike most conventional reservoir rocks, coal has low integrity and is very friable. The Mannville coal in the subsurface of Alberta, Canada, can be found at depths that vary between 600 m to greater than 2000 m. If we consider a cube of rock and its stress

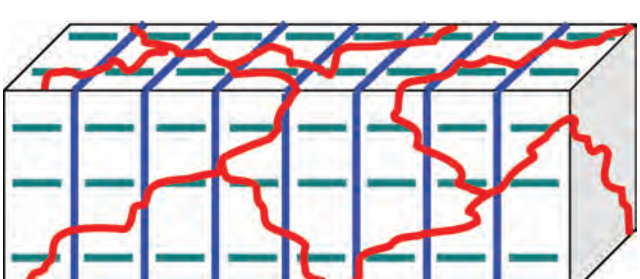

Fig. 1—Stylized depiction of a coal showing the face cleats (blue), butt cleats (green), and tectonic fractures (red).

Fig. 2—Outcrop of the Horsehoe Canyon formation, Paintearth Mine, Alberta. A thicker, poorly cleated inertinite rich coal overlying a thinner seam of well-cleated vitrinite rich coal.

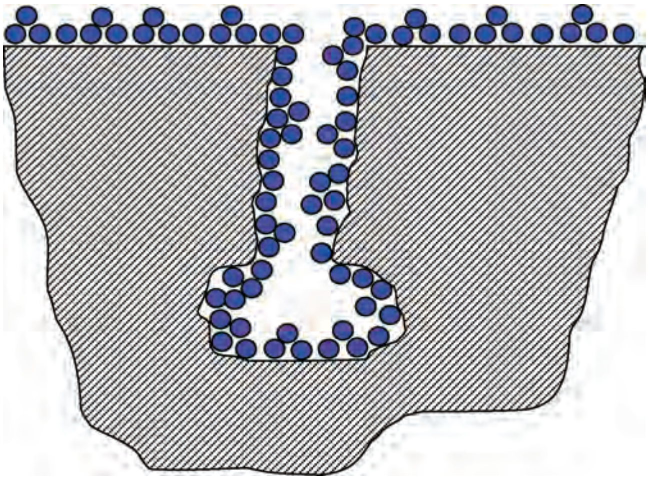

Fig. 3—Methane molecules adsorbed onto a cleat network of coal.

distribution, σ_v = the vertical stress, $\sigma_{Hz\ max}$ = the maximum horizontal stress and $\sigma_{Hz\ min}$ = the minimum horizontal stress, in coal found at depth, the $\sigma_{Hz\ max}$ is the largest stress field typically observed in the Western Canadian Sedimentary Basin. Coal has a Poissons ratio of as much as one order of magnitude higher than conventional rock, and the tendency to compress under sufficient load. This phenomenon contributes to a borehole instability mechanism when drilling in coal **(Fig. 4).**

In conventional reservoir rocks, the $\sigma_{Hz\ max}$ can be as high as six times the $\sigma_{Hz\ min}$. Therefore, the path of least impact when drilling horizontally is perpendicular to the maximum horizontal stress. In coal, the $\sigma_{Hz\ max}$ typically is only 1.6 times as much as the $\sigma_{Hz\ min}$. However, when combined with low strength of the coal, it stands to logic that the same principle applies. Field applications have proved this application to be true especially when tectonic fractures are present in coal (Palmer et al. 2005). Not surprisingly, with coal being such a heterogeneous material, exceptions to the previous guideline do occur. A narrow corridor between Barrhead and Fort Assiniboine (northeast of Edmonton in central Alberta) exists where differently orientated horizontal wells have successfully produced coalbed methane.

Drilling Considerations

Early drilling of horizontal wells in the Mannville coal in Alberta encountered tremendous borehole stability problems in most areas. However, innovation and experimentation led to a three-point system that proved quite successful. This system involves careful consideration of: (a) well trajectory/well design, (b) drilling practices, and (c) drilling fluid.

Well Trajectory. Because coal does not have a porosity and permeability in the conventional sense, the question of expected enhanced production from a horizontal well, compared to a vertical well, is ongoing. While high-density spacing of vertical wells followed by nitrogen fracturing of the coal proved to be economical in shallow coals, such as the Horseshoe Canyon in Alberta (Bastian et al. 2005), deeper coal horizons, such as the Mannville, proved to be more challenging. Poor production rates led to economics, which do not support high-density vertical well drilling for Mannville CBM wells. Essentially, the exposure to the desirable coal-cleating network is very limited in vertical wells. Horizontal wells are therefore designed and drilled to intersect as much fracture network as possible, especially the face cleats in thicker Mannville coal seams.

In Alberta, because of the presence of the Rocky Mountains arch, the $\sigma_{Hz\ max}$ has a northeast-southwest (NE-SW) orientation. Interestingly enough, the orientation of face cleats runs on the same NE-SW direction. Therefore, the wells that have recorded better success were designed with trajectories northwest-southeast (NW-SE) or southeast-northwest (SE-NW), achieving at the same time a near perpendicularity to the maximum horizontal stress and to the face cleats **(Fig. 5)**.

Practice has shown that coal does not support tight well radius, dog legs, or key seating. Therefore, at build angles, large-radius wells with very smooth curves produced significant benefits on drilling stable wellbores in coal.

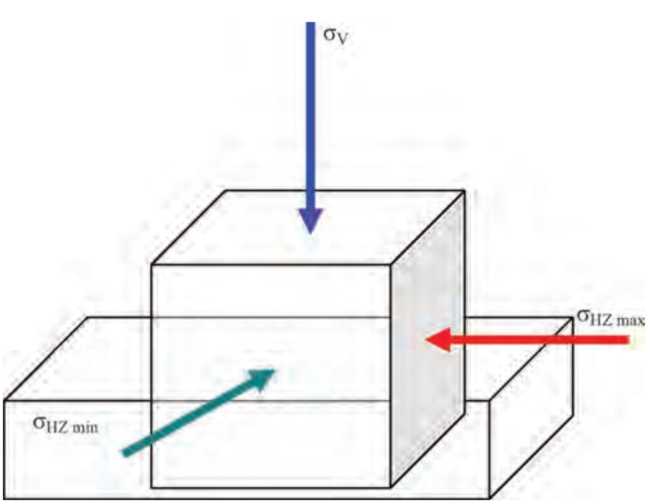

Fig. 4—Depiction of stresses and orientations. Vertical stress (blue), the maximum horizontal stress (red), and minimum horizontal stress (green).

Fig. 5—Map of Alberta showing stresses and cleating. Preferred orientation of the face cleats (blue lines), in a NE/SW direction, which is the same direction as the principle horizontal stress σ_{Hzmax}. Front line of the Rocky Mountains (curved red lines). The majority of the Mannville horizontal CBM wells have been drilled in a NW/SE direction.

Well Design. To date in Alberta, Canada, two distinct well profiles have been used: the "motherbore" design and the "classic" design. The motherbore design involves drilling a deviated intermediate hole through the coal, setting an intermediate casing, cutting a window, and drilling multiple horizontal legs into the coal seam **(Fig. 6).** A slotted liner is then run in each leg. The perceived advantages of this design relate to the possibility of drilling multiple horizontal legs as well as the use of a single dewatering pump for those legs. However, there are many disadvantages associated with this design as follows:

(1) Greater potential for borehole instability issues on the main hole around the bend caused by the well trajectory

(2) Slotted liners have to be set in the open hole, ~ 4 m to 6 m outside the window and typically in a water-sensitive shale

(3) Formation brine has to travel uphill around the bend to reach the window and the dewatering pump

(4) Drilling fluid used to drill the main hole becomes contaminated with cuttings other than coal, and those are introduced into the coal cleats, therefore increasing the potential for formation damage.

The second option is the classic design that involves drilling an intermediate hole deviated to ~90^0 in the coal and setting an intermediate casing. A ~1000 m horizontal leg is drilled with the toe uplifted ~2^0 compared to heel, such that gravity helps with the dewatering process. All the disadvantages from the previous design are alleviated—and in addition, this design allows for multiple horizontal legs in the same general direction, the "fork" design **(Fig. 7).**

In either design, it is imperative that the horizontal leg be maintained within the coal horizon, which in certain situations can be only 1 m thick. If the well trajectory bounces in and out of the coal, penetrating the underlaying and overlaying beds of typically water-sensitive shale and mudstones, two problems can occur: (a) a greater potential for borehole stability issues and (b) the introduction of formation-damaging solids to the coal reservoir leading to a reduction in production.

Drilling Practices. Until recently, coal formations have been regarded as nuisance formations by the drilling industry. As such, the conventional or "old school" drilling practices borrowed from drilling conventional rock do not apply properly to drilling in coal reservoirs. To understand why these practices do not apply, we need to understand the mechanisms involved in the borehole collapse while drilling coal.

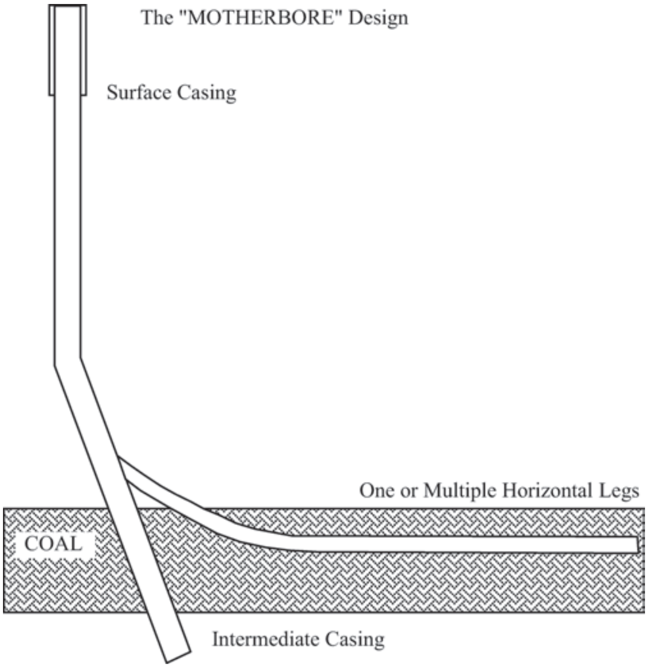

Fig. 6—"MOTHERBORE" design in which multiple legs are possible from one central casing string.

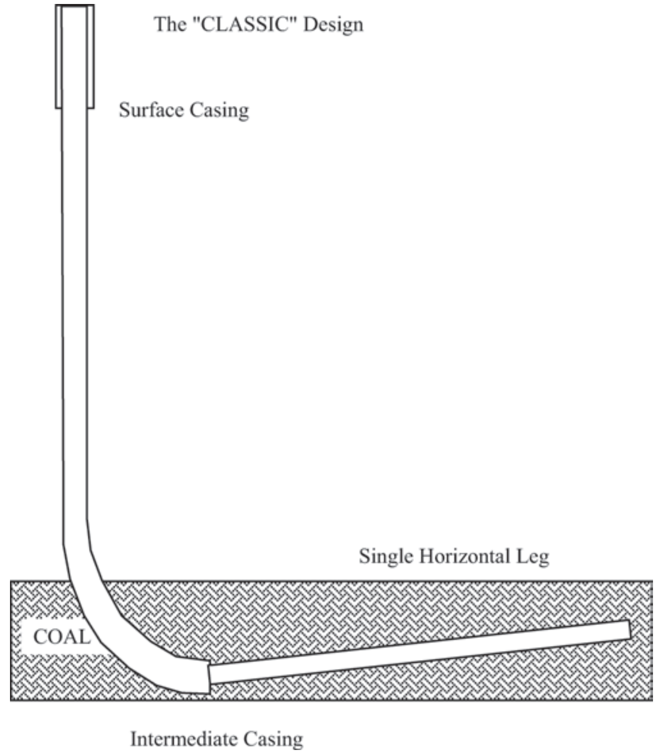

Fig. 7—"CLASSIC" CBM horizontal wellbore design with a single horizontal leg, which is often slightly inclined to assist in drainage of water during the production phase.

Assuming a portion of the borehole wall is taken from the upper hole in the horizontal section, and looking at it through a microscope—face cleats, butt cleats, and tectonic fractures are shown. The conventional way of thinking is to drill coal as fast as possible with inhibitive drilling fluids, brines, or inhibitive water with high pump outputs to clean the hole and case it before borehole stability issues develop. In highly fractured coal, this drilling approach proved to be a disaster and often resulted in stuck pipe and lost bottomhole assemblies.

Because of the micropermeability that impedes initial spurt loss across coal (i.e., identical to across shale), a filter cake cannot be built on the face of a coal. When drilling highly fractured coals with water/brine or conventional drilling fluids, these fluids invade the fracture network and carry two things: (a) pressure—which according to Bernoulli's Law in an incompressible fluid, distributes itself instantaneously and in all directions, and (b) particles—coal particles and other fluid components particles.

Drilling overbalance implies that the bottomhole pressure is greater than the formation pressure. However, when fluid penetrates the microfracture network, the formation pressure in the immediate vicinity of the wellbore becomes equal to the bottomhole pressure (BHP); therefore, the pressure below and above a coal chip contained within the fracture network equalizes, and the chip falls inside the wellbore. Typically, the more fluid lost to the formation, the deeper the pressure equalization that occurs and the greater likelihood for sloughing of coal cavings. Such cavings are usually blocky, with square edges, and can be quite large, up to 10 to 13 cm across. Sloughing happens in a relatively short period of time and in very large volumes. The old school approach has been to increase the mud density to "hold the well back," increase the pump output and fluid viscosity to clean the hole, mix conventional lost circulation material (LCM) to reduce the losses, and work the pipe across the tight zone in the wellbore.

On close analysis, none of these approaches produce the required results. When the mud density is increased with barite or calcium carbonate, the BHP vector is increased for a short period of time. However, at this time, the fractures in coal are partially propped open and more fluid penetrates inside them. In a matter of hours, the BHP dissipates to equal the formation pressure (FP), and the sloughing continues **(Fig. 8).** Increasing the pump output and fluid viscosity increases the BHP through pressure losses, but at the same time, increases fluid penetration with greater forces between the fluid and the chips of coal in the immediate vicinity of the wellbore. In fractured coal, higher hydraulic profiles are not desired. While the practice of increasing the pump output and mud viscosity for hole cleaning works in conventional rock, coal does not need such an approach. Because of the low-specific gravity of 1.2 to 1.5 in coal, CBM wells can easily be cleaned with water-based fluids of low viscosity. It is not the weight of the coal cuttings/cavings that pose a hole-cleaning issue but the size and volumes and the fast rate at which coal sloughs. Mixing a conventional LCM does not work either; especially, when rigid particles are involved. The hard, rigid particles act as proppant agents for the fractures thus leading to enhanced losses to the cleat network. In addition, if bridges are created with hard particles, they migrate deep inside the fractures therefore drastically reducing the permeability. Conventional LCM (e.g., fibers, cellophane, sawdust, etc.) are too big to create an effective bridge.

One of the common old-school approaches that does not work in coal is the working of the drillstring across the coal sections when signs of borehole collapse start to show at surface. Indications include increased torque and drag, increased pressure, tight hole, and/or reduced flow returns. The collapse has to do with the pipe movement and the hydraulics created by that movement. The procedure involves working the pipe through the troubled zone at increased speeds while pumping and rotating to clean the bridge formed by the sloughing coal. Surge and swab pressures generated by the pipe movement and the piston effect of the bit have a devastating effect on fractured coal and often result in more sloughing then stuck pipe with the loss of expensive directional drilling equipment.

The drilling approach (i.e., the new school method), proven to be very successful in fractured Mannville coals in Alberta, can be described by one word—*finesse*. The following are some of the new practices that aid in drilling CBM wells and specifically, horizontal CBM wells in the Mannville.

(1) Rigs with top-drives are preferred because of their ability to spend more time drilling and less time making connections, tripping, surveying, and other nondrilling functions. (2) Control drilling at rates of <15 meters (m/hr) demonstrated far better success than the drilling at the maximum rate of penetration (ROP) that the bit can make in the coal sections. When the ROP is controlled, signs of borehole instability are detectable and can be corrected before becoming a serious drilling problem.

(3) Trip speeds have to be controlled at wells below 0.5 meter/second (m/s) to alleviate the potential for surge and swab. (4) Drilling bits ideally meet three criteria: (a) no nozzles, (b) back-reaming capability, and (c) generation of large coal cuttings. Nozzles are not required, because control drilling is applied at a relatively low ROP. In coals, there is generally no need for high-nozzle jet velocities to achieve an ROP of 15 meter/minute (m/min). Also, bits do not ball in coal. The back-reaming capabilities are vital to successful drilling. When the first signs of borehole instability are noted at the surface, continuous back reaming at reduced pump outputs is recommended through the troubled zone. Then, incremental reaming at normal pump output is recommended while adjusting the mud properties. Typically, there is no need to increase the mud density or the mud viscosity, when the right mud is used. The reasoning for large cuttings generation has to do with formation damage. Fine coal has a very large surface area, is chemically charged, and can penetrate inside the fractures and pose a serious formation damage threat. Fine coal has the ability to bind the components of the drilling fluid, making it less effective to a new wellbore and posing other drilling risks.

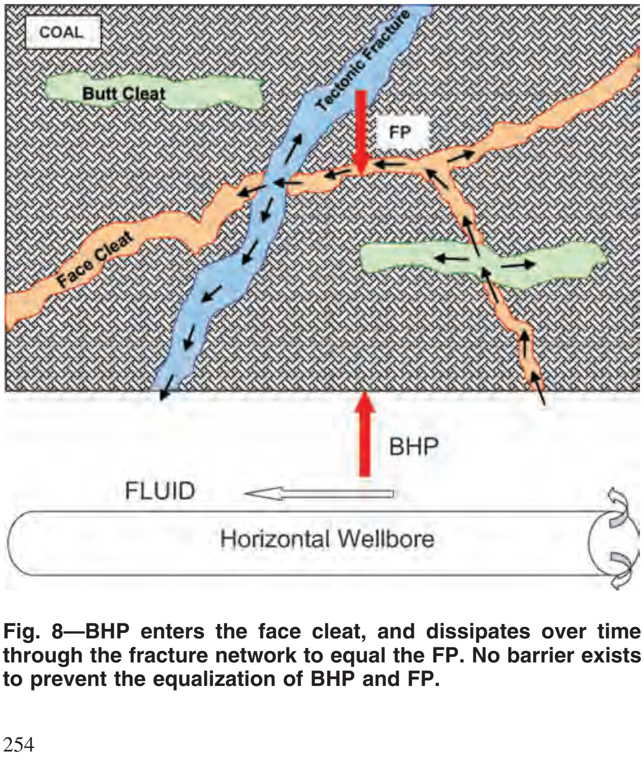

Fig. 8—BHP enters the face cleat, and dissipates over time through the fracture network to equal the FP. No barrier exists to prevent the equalization of BHP and FP.

Drilling Fluids

To date, a new drilling fluid has been used to successfully drill more than 30 CBM Mannville horizontal wells by 9 operators in Alberta, Canada, with horizontal legs between 750 to 1200 m, all reaching the planned total depth.

The success behind this new drilling fluid resides in its innovative approach. If a filtercake cannot be achieved across the coal, then the next best thing is a series of intimate, very low-permeability surface bridges, or mats, across the intersected fractures, face cleats, and tectonic fractures. The fluid achieves this by exploiting the strong surface electrical charge of the coal. The filtercake building materials/chemicals in the drilling fluid are attached to the face of the coal by an electrical charge attraction, rather than depending solely on a pressure differential between the circulating fluid and coal formation pressure. To differentiate this "filtercake" on coal, the authors refer to the process as "bridging" or "matting."

There are two versions of the newly developed drilling fluid. One is a combination of bentonite, natural polymers, and other proprietary products and is intended for cased hole completions. The other one is formed of a combination of natural polymers and other proprietary products, and intended for openhole completions. This second version of the fluid can be destroyed with a breaker.

When density is required, the fluid is built on a brine backbone in which density is achieved without introducing hard particles to the system.

As drilling progresses in fractured coal, the polymers within the fluid attach to the ends of the electrically charged fractures creating "bridge heads." In combination with the other products in the fluid, the polymers form surface bridges across fractures, sometimes referred to in the industry as "buttons." These are multilayer flexible mats, because they are formed of flexible materials only. Field application has demonstrated the flexibility of the bridges. When hydraulics values are increased, it is possible to have 3 to 4 m^3 of fluid lost to the hole, only to be regained on connections.

By creating these very low-permeability bridges across the fractures, the drilling fluid maintains a constant positive pressure ($\Delta P = BHP - FP$) on the walls of the wellbore. If the pressure equalization stops, then the borehole instability is alleviated **(Fig. 9).**

The drilling fluid alone cannot alleviate drilling problems. If the drilling practices are incorrect or if the well trajectory is not carefully planned to mitigate intersecting the face cleats with the localized rock stress distribution, drilling problems can occur.

Completion/Stimulation

As previously suggested, two types of well completion have been performed to date on wells drilled with this innovative drilling fluid: openhole completion and cased-hole completion.

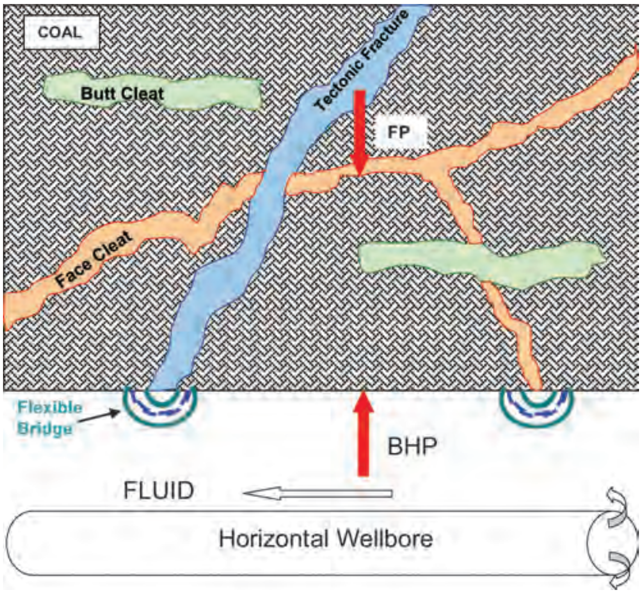

Fig. 9—Flexible bridge/mat is formed across the face cleat and tectonic fractures, thereby preventing fluid/pressure penetration. BHP is maintained higher than the FP, with resulting borehole stability and decreased formation damage.

In the case of cased-hole completion, at well total depth, a liner is run and cemented in the horizontal section. The hole is then perforated, and a nitrogen frac operation is conducted.

In the case of openhole completion, at well total depth, a slotted liner is run. The horizontal section is displaced to a breaker that destroys the viscosity of the drilling fluid. The challenge is to obtain maximum displacement of the breaker into the annulus, and a number of methods have been tried with different degrees of success. With all methods, the better the displacement efficiency, the better the drilling fluid viscosity reduction. After the horizontal section is displaced to the breaker, the hole is blown dry from above the coal formation to the surface to take the hydrostatic pressure off the well. While the breaker works to remove the drilling fluid mats, it is important not to push the residues into the cleat/fractures.

If, after the bridges are broken, the initial production tests are lower than the estimated potential, two types of stimulation are usually applied. The first stimulation involves the use of a downhole tool called an "acoustic horn." This tool has the ability to emit ultrasound waves and channel them along fractures. The invading particles in these fractures (i.e., field application demonstrated that they are formed primarily of very fine coal) are "shaken" to the point where their connections to the fracture wall are broken. When this tool is used in backflow conditions (i.e., there is a water flow from the coal reservoir to the wellbore), the loose particles are brought into the wellbore, and the fractures are cleaned, therefore a permeability increase is obtained. When applied correctly, this method produces good results.

The second type of stimulation involves a "ballooning" of the coal formation around the wellbore using nitrogen, followed by a fast release of the pressure to obtain cavitation of the hole around the liner. As such, a potential damaged zone around the wellbore is penetrated, and a larger fracture network with higher permeability is obtained thereby increasing the production. As one field application demonstrated, this method had to be carefully planned and conducted. If the fracture is not controlled, it can tap into an adjacent oil-bearing formation. Coal is oil wet, and desorption does not appear to take place once the coal has been coated by oil.

A third type of stimulation of CBM wells in deep coals is primarily reserved for those wells drilled with conventional drilling fluids. It involves conventional fracturing with a proppant carried by a fluid, such as polymeric water or foam. Although extensively tried, this method does not appear to produce very positive results in the Mannville coal. However, the wells did not produce methane as hoped. It is known that coal surface has a strong electrical charge, and it was expected that strong chemical interactions would take place between the formation and the carrier fluids. Adherence of polymers and especially of surfactants (i.e., present in the foams) to the fracture walls were suspected as the number one culprit for impeding methane desorption. In summary, this method did not produce the desired effect.

Field Results

While an in-depth understanding of coal geology properties and rock mechanical considerations lead to the development of a drilling fluid and breaker system, the field performance determines the success of those developments. The following discussion focuses on three horizontal wells drilled within the Western Canadian Sedimentary Basin.

Two of the three wells were drilled with the new drilling fluid system; the other drilled with a more conventional polymer system. While all the wells were stimulated with N_2 gas to enhance fracture conductivity, one of the wells was pretreated with the breaker system.

The three wells were drilled in central Alberta, between Calgary and Edmonton, at depths of 1400 to 1800 m. Each well was the "classic" wellbore design, as shown in **Fig. 10.**

The theory of bridging the coal cleats and tectonic fractures Re applicable to any CBM field, independent of the water content in the coal. The field results subsequently discussed, focus on the Mannville coal reservoir, which is exploited by drilling horizontally within the coal reservoir.

In some drier CBM reservoirs, such as the Horseshoe Canyon Play (Bastian et al. 2005), where water production is not required to produce the methane gas, the majority of these wells are drilled vertically and thus do not generally warrant a bridged drilling fluid over the few meters of coal seams encountered.

Drilling Results

The three wells were drilled as follows: a simple gel chemical fluid was used to drill the surface hole. The first and deepest of the three wells drilled with flocculated water was the fluid from under the surface shoe to the intermediate hole kickoff point (KOP); while the other two wells, both drilled to similar shallower depths, used an amine-enhanced flocculated water. From KOP to the intermediate casing point, the first well was drilled with a partially hydrolyzed polyacrylamide (PHPA)-based polymer mud. The other two wells were drilled with the special CBM system to enhance wellbore stability through any coal sections.

The horizontal sections of the second and third wells were drilled with specially designed fluids as previously described. These fluids were engineered to both stabilize the wellbore and minimize any impairment within the horizontal coal seam. The first deeper well used a conventional polymer drilling fluid, similar

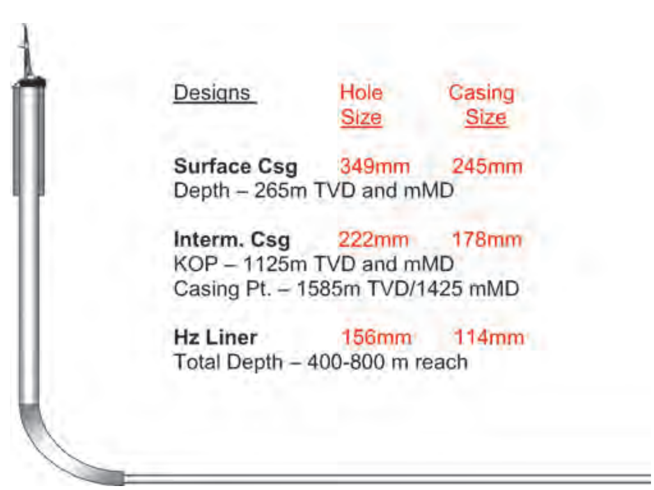

Fig. 10—Generic wellhole/casing design for coalbed methane wells drilled.

to those commonly used in horizontal carbonate reservoirs. A successful drilling program is considered to be one in which borehole stability is maintained, logs are obtained, and the casing/liner is successfully run and cemented into place.

Horizontal Drilling Results. The results from drilling the horizontal sections are summarized in **Table 2.**

The first well, drilled with the more conventional polymer mud, was drilled 403 m horizontally in the coal seam. The drilling fluid was a basic mixture of polyanionic cellulose (PAC) and Xanthan polymers, with sized calcium carbonate added as a bridging material. As drilling commenced, the hole started showing signs of instability, and as a result, drilling was concluded.

Upon reaching total depth (TD), additional problems of stuck drilling assembly, difficulty getting the liner to bottom, reaming and cleaning in the coal, and rerunning the liner were encountered. Large volumes of fine coal were released from the well. A total of 4 days were lost to poor hole conditions.

The second and third wells were drilled with the customized drilling fluid designed for horizontal CBM wells. The only problem encountered was 20 m^3 of drilling fluid lost in the coal seam on well #2. There was no evidence on surface (pit volume changes) of the coal taking large volumes of drilling fluid while drilling and then returning this fluid under tripping or other lower pressure practices. This confirmed the efficiency of the flexible bridges across the coal fractures and cleats.

The slotted liners on wells #2 and #3 were run to TD without problems, and hung in place. Borehole instability was not seen, and no torque or drag indications were noted.

Completion and Fracturing of Field Wells. As previously explained under the fluid design section of this paper, it is important to "mat" the cleats with a properly designed system, which acts to both stabilize the wellbore and minimize mud and filtrate invasion into the cleats. This "minimization" promotes easier cleanup of the wellbore.

In the two shallower true vertical depth (TVD) wells previously described, the matting system worked very efficiently to bridge the cleats and prevent any instability from occurring. This same matting material needs to be removed before completion and/or stimulation. An N_2 fracturing job is more effective if the cleats are clear from debris.

All three wells in this area were fractured using N_2 gas. The fracturing was not caused by a poor production response, but was planned at the outset of the well. The following discussion focuses on the general methods employed to complete/stimulate each of the wells.

The first deeper well was run with a nonslotted liner. Once perforation was completed over selected intervals, an N_2 fracturing job was completed. The well was put on test and production.

A cemented liner was run on one of the two shallower wells, thus perforation was required. Following the drilling phase, the liner was scraped out with fresh water and then reverse circulated to cleanout the wellbore. The horizontal section was then blown down with N_2 to remove any liquid. An N_2 fracture of 150,000 SCM was placed. Additional perforations were shot and another 120,000 SCM of N_2 gas was used to perforate.

The second, shallower well, with a preslotted liner in place, was treated in a different manner. After the well was blown dry on coil, 18 m^3 of breaker was spotted and left in place for ~10 days. A coiled tubing unit cleaned out the well with N_2 working from heel to toe. A total of 29 m^3 of fluid was recovered. A ballooning N_2 placement job, similar to the one previously discussed in the paper, was done on this CBM well.

Conclusions

The following are the key learnings from this work:

- A thorough rock mechanic understanding of the coal reservoir is crucial to well placement. For Manville wells in Alberta, where the face cleats run in a NE-SW orientation, the ideal horizontal well placement is perpendicular to those face cleats.
- Horizontal well design depends on the number and direction of the horizontal legs, as well as the stability of the formation directly overlying the coal.
- Proper drilling practices are very important to ensuring wellbore stability within the coal section. Items, such as controlled drilling rates, trip speeds, bit selection, etc., affect the stability of the coal.
- A "matting" drilling fluid system was designed to minimize the pressure leakoff from the wellbore into the formation. A breaker was designed to remove the matting/bridging material once drilling is completed.
- The "mats" are formed from the attraction of the electrical charge on the coal and the drilling fluid additives.
- Two kinds of matting drilling fluids have been developed, one with a polymer base and a second with a bentonite base.

Nomenclature

σ_v = vertical stress, mPa
$\sigma_{HZ\max}$ = maximum horizontal stress, mPa
$\sigma_{HZ\min}$ = minimum horizontal stress, mPa

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TABLE 2—SUMMARY OF DRILLING DATA FOR THREE HORIZONTAL WELLS DRILLED IN MANNVILLE COAL

	Well #1	Well #2	Well #3
m drilled horizontal	403	708	792
Days on section to rig release	9.3	5.8	3.5
Drilling fluid	conventional polymer	polymer + bridge/mat	polymer + bridge/mat
Lost time	4.0 days	0.15 days	none
Problems	- stuck pipe - rerun liner - reaming - planned TD not met	- lost circulation	none

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SI Metric Conversion Factors

bbl × 1.5898	E–01	= m^3
ft × 3.048	E–01	= m
in. × 2.54	E–02	= m

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