

FRACTURING TECHNOLOGIES FOR IMPROVING CMM/CBM PRODUCTION

1.0 Introduction

While the majority of today's CMM/CBM production is produced by oil and gas companies, many of the techniques presently used in the CBM industry originated in the coal mining industry in the early to mid-1970's. During this time, the U.S. Bureau of Mines (USBM) was seeking to develop methods for reducing the levels of methane in the mine workings of deep (500-700 meters), longwall mines in Alabama and Virginia. The primary goal of this research was to improve mine safety.

Early efforts, such as those at the Oak Grove Mine in Alabama, successfully demonstrated that vertical, hydraulically fractured wells drilled in advance of mining could lower methane levels in the mine workings by up to 40%. However, a roof fall in a Pennsylvania mine after a hydraulic stimulation was mined through raised serious concerns among the coal mining industry as to whether hydraulic fracturing damaged the roof rock, creating unsafe mining conditions. Although it was later determined that the roof fall was due to pre-existing joints in the roof rock, the mining industry continued to question the safety of hydraulic fracturing in mined areas.

To address these concerns, the USBM initiated an extensive research program to determine whether hydraulic stimulations adversely affected mining conditions (Diamond and others, 1987). Their research consisted of 22 hydraulic fracture treatments that were mined-through to directly observe the effects on the coalbed and roof strata. Fractures were observed to propagate into overlying strata in nearly half of the treatments studied, but most were interpreted as penetrations into pre-existing planes of structural weakness. No roof falls or adverse mining conditions were encountered that could be attributed to the stimulations.

This work convinced a number of coal companies (Consol, Jim Walters, Island Creek) to employ vertical, hydraulically fractured wells as a degasification technique in advance of mining at their deep, gassy longwall mines. The bulk of the CBM wells drilled and completed today are still hydraulically fractured in the conventional manner, although new techniques for conducting hydraulic fracture treatments (such as coiled tubing fracturing) and alternative fracturing methods (explosives) are being tested. These new techniques offer the promise of lower cost stimulations, and could allow marginal CMM/CBM prospects to be developed.

2.0 Description of Fracturing Technologies

Fracture stimulation technologies for enhancing well deliverability can generally be categorized in three types, according to the rate at which energy is applied to the target horizon to induce fracturing:

- At one extreme, *hydraulic fracturing* involves a relatively low rate of loading, resulting in a two-winged vertical fracture extending outward from a well, approximately 180° apart and oriented perpendicular to the least principal rock stress, (Figures 1 and 2(a)). Because of the creation of a single fracture, and the ability to pump large volumes of fluids at (relatively) low rates, the potential penetration for the fracture into the formation can be large, hundreds of feet in many cases. This technique is currently the most widely used in the CMM/CBM industry.
- On the other extreme, *explosive fracturing* involves a very rapid loading of the target formation, resulting in a highly fractured zone around the wellbore, but usually to a radius not exceeding 10 feet (Figures 1 and 2(c)). Because the peak pressures exceed both the minimum and maximum horizontal in-situ stresses, a radial fracture pattern is created, which can be an advantageous fracture geometry where near-wellbore stimulation is the primary objective.
- Between these two extremes is *pulse fracturing*, which is characterized by peak pressures exceeding both the maximum and minimum in-situ stresses (also creating a radial fracture pattern) (Figures 1 and 2(b)). This technique results in multiple vertical fractures extending radially from the wellbore, with penetrations on the order of 10 to 20 feet in some cases.

Two of these fracturing techniques -- hydraulic and pulse fracturing -- hold promise for CMM/CBM development. Within these two broad categories of fracturing technologies, five technologies are considered: three are considered hydraulic in nature (liquid CO₂ with proppant, straight nitrogen without proppant, and coiled tubing fracturing) and two are pulse in nature (propellant and nitrogen pulse).

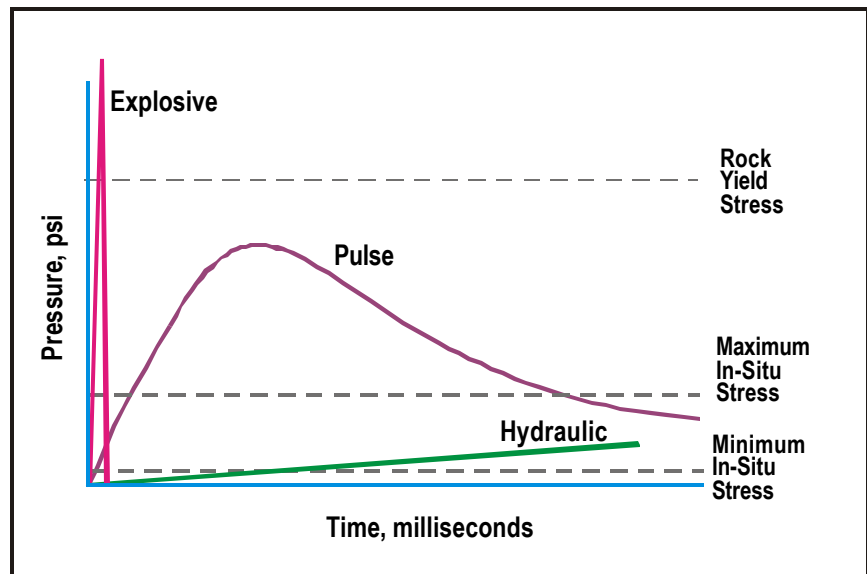
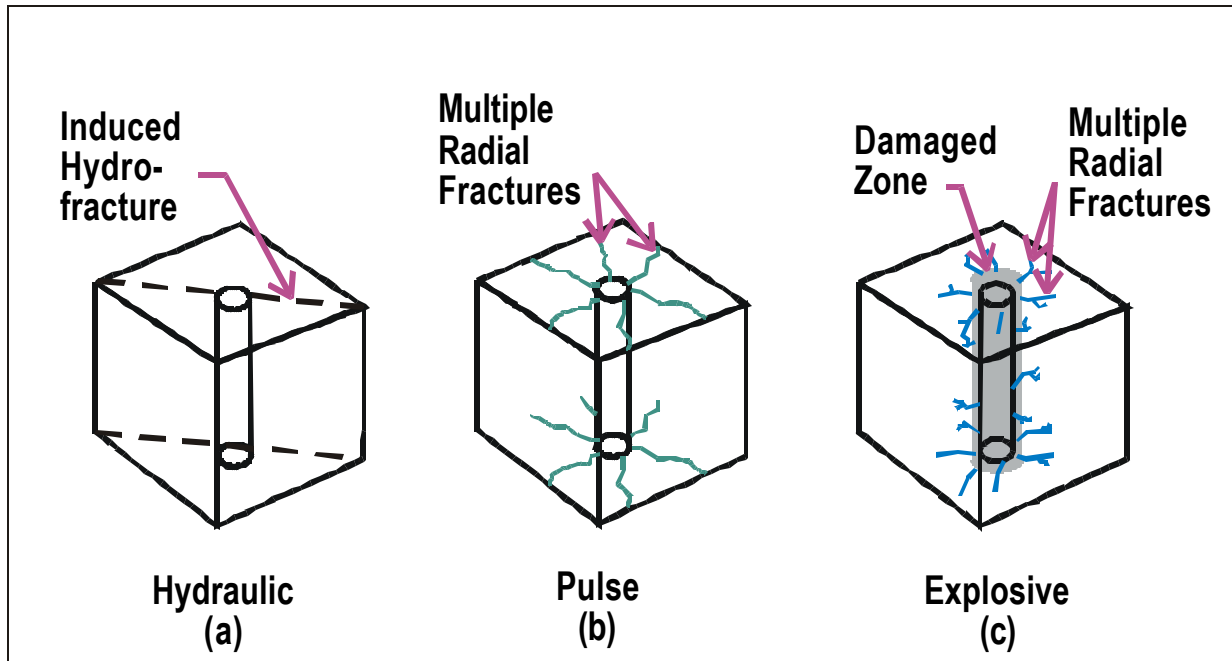


Figure 1. Comparison of Pressure Histories for Rock Fracturing Techniques.



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Figure 2. Comparison of Created Fracture Geometries for Rock Fracturing Techniques.

2.1 Hydraulic Fracturing

Hydraulic fracturing involves the creation of a single, planar, vertical fracture (except in shallow zones where horizontal fractures can be created) which extends in two wings (180° apart) from a wellbore. The fracture is created by pressurizing the wellbore with a fracturing fluid until the reservoir rock cracks, and then extending that fracture by continued injection of fluid. A solid proppant, normally sand, is carried with the fluid such that when injection ceases and the fracture begins to close, it remains propped open by the proppant left behind. This creates a highly conductive flow path for reservoir fluids to be rapidly produced from the reservoir.

Hydraulic fracturing is utilized to stimulate production from low permeability reservoirs, requiring deeply penetrating fractures in the range of 200-500 feet per wing. Hydraulic fracturing with water (mixed sometimes with a light gel) and sand is currently the most widely used fracturing technique in the CMM/CBM industry.

2.1.1 Fracturing with Liquid Carbon Dioxide (CO₂) With Proppant

The principal disadvantage of the water-based fracturing fluid systems currently in use for coal seams is that they have the potential to create substantial damage to the reservoir, and also introduce extra fluid into a system to be de-watered. Formation damage can take a variety of forms, including a reduction in the relative permeability to gas, gel and chemical residue blocking the pore spaces of the reservoir and/or proppant pack, or water-induced swelling of formation clays. Methods to address

these problems have been the topic of considerable research.

One approach to avoid formation damage altogether, and which has a long track record in Canada, is fracturing with liquid CO₂. The principal benefits of utilizing liquid CO₂ as a fracturing fluid are the elimination of unfavorable relative permeability effects, the non-existence of gel and other chemical residues, and the elimination of water-induced clay swelling. These complications are eliminated because liquid CO₂ is a non-aqueous, non-damaging fluid. In coal seams, this technique can provide a small amount of production enhancement through the introduction of CO₂ into the reservoir.

The principal difference between fracturing with liquid CO₂ and other fluid systems is in the blending requirements. Proppants and CO₂ must be mixed in a purpose-built pressurized blending system, of which only a few exist today. Because of the need to mix the liquid CO₂ and proppant under pressurized conditions, proppant must also be stored and transferred to the blending tub under pressure. This places a practical limit on the amount of proppant that can be used with this system, which is based on the capacity of the pressurized proppant storage bin on the blender (about 40,000 pounds).

Application of CO₂ Fracturing to CMM/CBM The principal benefit of liquid CO₂ fracturing for CMM/CBM reservoirs is identical to that for gas production wells -- the elimination of formation damage and rapid cleanup. This may be particularly significant since many CMM/CBM wells require six to nine months of de-watering for a well that has been fracture-stimulated to clean-up and begin showing significant gas production. By providing a more immediate benefit, liquid CO₂ may be of particular value for CMM/CBM wells drilled ahead of mining to accelerate the degasification of the coal.

2.1.2 Fracturing with Nitrogen

Fracturing with gaseous nitrogen is also a viable stimulation technique for formations potentially sensitive to aqueous-based fracture fluid systems such as coal seams. In this case, nitrogen is pumped as a cryogenic liquid and then heated to form a gas prior to being injected into the well. Fracturing mechanics occur as in any other hydraulic fracturing technique, the only difference being that the fracturing fluid is a gas. Unfortunately, pumping nitrogen as a gas normally eliminates the possibility of transporting proppants, and as such, nitrogen fracturing can be classified as a proppantless, non-reactive stimulation technique.

Application of Nitrogen Fracturing to CMM/CBM As with fracturing with liquid CO₂, the principal benefit of fracturing with gaseous nitrogen is the non-aqueous, non-damaging nature of it, particularly in water sensitive formations. Many CMM/CBM operators have indicated that fracturing cleanup times can be very long -- several months in some cases -- and it is in these environments that nitrogen fracturing may be of greatest benefit. Also, numerous studies have also demonstrated that the gels and other additives used in conventional hydraulic fracture treatments can be highly damaging to coal reservoirs. The use of nitrogen as a fracturing fluid may also assist in the production of CMM/CBM through the enhanced production properties the nitrogen has with methane in the coal

seam reservoir.

2.1.3 Coiled Tubing Fracturing

Coiled tubing is being increasingly used in the oil and gas industry for a number of applications, including slimhole drilling, fishing operations, remedial treatments and hydraulic fracturing. In coiled tubing operations, a continuous roll or “coil” of tubing is used in place of drill pipe or tubing strings to conduct the desired operation. Coiled tubing operations offer several advantages over conventional methods, including portability, a small well site footprint, and the elimination of a rig.

The portability and small footprint of coiled tubing operations make it an attractive option for CMM/CBM fracturing operations. Coiled tubing fracturing also allows for the fracturing of multiple coal seams simultaneously with the convenience of constant well control. Hydraulic fracturing operations that once required two to three days can now be completed in one day. The ability to complete multiple zones in a single trip mitigates the risk of wellbore damage from the multiple well interventions and downhole tool runs associated with conventional fracturing operations.

Cost savings are realized in several areas, including the need for workover rigs and the elimination of bridge plug for zonal isolation. Manpower costs are also significantly reduced, as the time required for fracturing operations can be more than halved.

Several service companies currently offer coiled tubing fracturing services including Halliburton (Cobra FracSM), Schlumberger (CoilFRAC), and BJ Services. Because fracturing through coiled

Cobra Frac Service Increases Cumulative Gas Production by 50% and Cuts Costs by 8%

Operator's Challenge

Barrett Resources needed to increase early production and effectively stimulate many small coal intervals in their Raton Basin coalbed methane asset area. Previous large stage fracture treatments provided only average results with no assurance that all the coal was being effectively stimulated. The CBM wells were producing from the Raton and the Vermejo formation. Wells are typically twinned with separate Raton and Vermejo horizons and from 1,500 to 2,500 ft TVD and 95^F to 110^F BHT.

Cobra Frac Service uses an optimized integrated system of tools and coiled tubing to isolate and fracture all coal zones in one trip in the well. This saves time, reduces total completion cost, and provides better early well production.

Economic Value Created

Barrett's first 14 wells on production for 30 days provided an average of 25 to 137 MCFD more production than conventionally fractured wells done previous to Cobra Frac service on the lease. In addition, the Cobra Frac stimulated wells were completed in only 4 days compared to 7 to 10 days using conventional stage fracturing. The results: production is on line faster, total completion costs are down 8%, and cumulative production is 50% more than what it was prior to Cobra Frac Service. Since the September 2000 introduction of Cobra Frac service in the U.S., Halliburton has not experienced any lost-in-hole coiled tubing or lost-time accidents.

tubing is relatively new to the CMM/CBM industry, there is little published data on its efficacy in CMM/CBM reservoirs. The press release by Halliburton (see below) summarizes the benefits of coiled tubing fracturing on one CBM project in the Raton Basin.

2.2 Pulse Fracturing

The primary difference between pulse and hydraulic fracturing is the rate at which energy is applied to the formation to create fractures. In hydraulic fracturing, this rate is relatively low and results in the extension of a single, relatively long fracture perpendicular to the least principal in-situ stress. Pulse fracturing involves much more rapid energy discharge, creating a series of vertical fractures, each perhaps 5 to 20 feet in length, propagating radially outward from the wellbore (Figure 3). One pulse fracturing technique that has been successfully applied in a variety of damage-removal type applications is propellant gas fracturing.

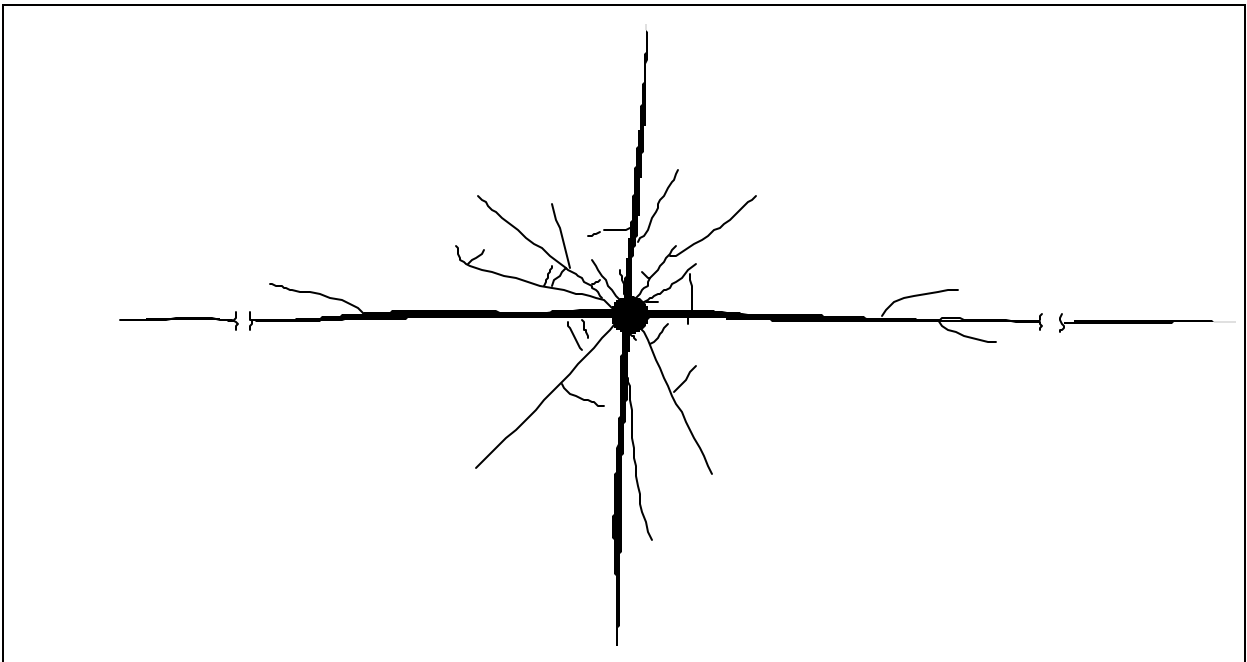


Figure 3. Conceptual Model of Pulse Fracturing Results

2.2.1 Propellant Fracturing

Propellant fracturing, also known as controlled pulse fracturing, tailored pulse loading or high energy gas fracturing, involves the use of a wireline run, electrically ignited propellant (similar to solid rocket fuel) which is placed across the formation to create a high pressure pulse. This pulse of gas creates multiple short (5 - 20 ft) radial fractures in the formation, which connect to the wellbore and are confined close to the zone stimulated. In addition, propellant fracturing avoids the resulting wellbore damage often associated with explosive fracturing.

In addition to minimizing near-wellbore damage, another reason that propellant fracturing may apply to CMM/CBM wells is that vertical fracture growth is limited and generally restricted to about one-half the horizontal length of the fracture. The reason is that the fracture growth is gas-dynamic, and there is not time nor energy available for the unrestricted height growth that can occur with a large hydraulic fracture. Therefore, knowing the distance to the reservoir cap, a propellant treatment can be designed to virtually guarantee that breakthrough will not occur. With recent concerns over the possibility that hydraulic fracturing may contaminate aquifers (LEAF vs. EPA), this technique could be used to ensure the fracture does not communicate with the overlying aquifers.

One of the disadvantages of propellant technology is that the created fractures are left unpropped, and hence are susceptible to closure and plugging.

2.2.2 Pulse Fracturing with Nitrogen

Another pulse fracturing approach, utilizing nitrogen, may have greater applicability to CMM/CBM wells. Pulse fracturing with nitrogen is a process similar to propellant fracturing for initiating short multi-directional fractures. Commonly done as part of well perforating, it has also been used for well remediation.

Immediately following the treatment, the unpropped fractures will almost certainly improve well performance. However, with no proppant to hold the fracture open, the benefit from the treatment will (at least partially) deteriorate over time. A variation on this process is to place a small slug of viscous, proppant carrying gel in the bottom of the well, and thus force this slurry through the perforations at high rates and pressures. The use of this process has been primarily aimed at placing resin coated sand in the perforations in sand production prone areas; however, this should also leave a small, propped fracture outside the wellbore, thus retaining the stimulation effect for a longer time.

3.0 Impact and Economics of Fracturing on CMM Recovery and Use

The use of fractured vertical wells is proven to be an effective method for reducing the methane content of coal seams in advance of mining, thereby ultimately lowering methane emissions to the atmosphere. As discussed in the introduction, a project at the Oak Grove mine in Alabama demonstrated that vertical, hydraulically fractured wells drilled in advance of mining could lower methane levels in the mine workings by up to 40%.

A similar study at Oak Grove (Diamond and Others, 1989) documents that the 23 vertical, hydraulically fractured wells at the Oak Grove mine produced 73% of the original gas in place in the Blue Creek Coalbed over the ten year period. Methane reductions of 79% and 75% were achieved in the overlying Mary Lee and New Castle seams, respectively, over the same period.

One of the main advantages of vertical degasification wells is that they generally produce pipeline quality methane without the need for extensive processing. The disadvantage to fractured vertical wells is that they are more expensive to drill and maintain than in-mine or GOB wells. Hydraulic fracturing can represent one-third to one-half of total well costs.

Based on limited published information, it appears that new fracturing technologies hold the potential for lowering fracturing costs, thus allowing CMM/CBM that are marginally economic to be developed. According to the previously cited press release by Halliburton, fracturing through coiled tubing can lower fracturing costs by 8%. The largest cost savings would be realized in pulse-type fracturing, as their cost is on the order of 25% to 30% of that of hydraulic stimulations.

Potential Benefits from Fracturing for CMM Recovery. Active methane recovery operations are currently in place for most of the gassiest mines in the U.S. (i.e., those producing more than 5 MMcf per day of vented emissions). Recent efforts utilizing hydraulic fracturing in wells drilled in advance of mining lowered methane levels in the mine workings by up to 40%. Assuming that the application of fracturing technology in active mines currently emitting less than 5 MMcf per day could reduce methane levels by 20% to 40%, then total methane emissions from these mines could be reduced by 4.7 to 9.4 Bcf per year.

Lowering the cost of fracturing technologies in coal mine degasification applications could substantially expand efforts to produce methane from coal seams in advance of mining. For example, a typical CMM well in Alabama today costs on the order of \$200,000. With current technology, fracture stimulation costs are on the order of \$50,000 to \$80,000, adding 25% to 40% to total well costs. Reducing fracturing costs by half would reduce total well costs by 9% to 16% (assuming no drilling cost reductions would also result from improved technology). Reducing the costs of CMM wells could substantially increase their utilization for coal mine degasification applications.

For example, reduce fracturing costs could encourage the 18 gassiest mines in the U.S. to more aggressively pursue CMM recovery activities, and, if these activities result in 10% greater recovery of methane from the mine, this would amount to reduced emissions on the order of 6.4 Bcf per year. Moreover, if these lower-cost fracturing technologies become viable in the less gassy mines (those currently emitting between 0.1 and 5.0 MMcf per day), and this results in an additional recovery of 10% of the emissions from these mines, another 2.3 Bcf per year of CMM emissions could be avoided.

4.0 Limitations/Barriers to Implementation

The limited use in the CMM/CBM industry of the different fracturing technologies described in this report is in part because of the lack of documented field trials in coal seams. The oil and gas and mining industries can be slow to adopt new technologies, especially when the technologies will be displacing “tried and true” methods such as hydraulic fracturing. Also because there is not widespread use of the technology as yet, the service companies only have a limited number of units to perform these types of fracturing jobs (for example, there are only 3 units capable of CO₂ fracturing in North America).

There do not appear to be any legal or regulatory constraints facing the development of this new generation of fracturing technologies. In fact, with their smaller footprint and shorter time frame required to conduct the work, these technologies may help mitigate environmental and permitting concerns.

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