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Hydraulic Fracturing for Coal Seam Gas (CSG) Stimulation in NSW

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Report EP122949
30 April 2012

Prepared for the New South Wales Office of the Chief Scientist and Engineer

CSIRO Earth Science and Engineering

Citation

Jeffrey, RG (2012) Hydraulic Fracturing for Coal Seam Gas (CSG) Stimulation in NSW. CSIRO, Australia. Report EP122949, 15 pages.

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1 Introduction and Background

This report provides a description of hydraulic fracturing and general information about the use of hydraulic fracturing in Australia and New South Wales. This report has been written at the request of the Office of the Chief Scientist and Engineer of NSW.

Hydraulic fracturing has been used in the petroleum industry since 1947 (Howard and Fast, 1970) to stimulate oil and gas wells, allowing them to be produced at higher rates and allowing more of the in-place hydrocarbons to be recovered (Veatch, et al. 1989). Hydraulic fracturing for stimulation was first used in Australia in 1969, in the Cooper Basin (McGowan et al., 2007). Notes on the history of coal seam methane and fracturing in Australia are included as Appendix A.

Whether applied to a conventional oil or gas well in a sandstone reservoir or to a coal seam methane well accessing a coal seam, the purpose of the hydraulic fracture stimulation is to create and prop open a fracture in the reservoir that then provides a large surface area through which reservoir fluids can be produced and a conductive channel (the propped hydraulic fracture) through which these fluids can flow easily back to the well. Once in place, the propped hydraulic fracture acts like a drain. As the pressure in the well is reduced by production, the low pressure penetrates along the conductive hydraulic fracture so that the reservoir fluids, which are at a higher pressure, flow from the rock through the sides of the fracture and into the propped fracture channel and then along it to the wellbore. Thus, much higher production rates can be achieved after fracturing. Production rate increases of a factor of two to five for vertical wells and by a factor larger than 5 for multiple fracture stimulations along horizontal wells, are typical. Wells that are drilled into low permeability reservoirs, which would otherwise be uneconomic, can be produced after fracturing, which allows resources that would otherwise be uneconomic to be recovered.

1.1 The hydraulic fracturing process

Hydraulic fracturing is the process of creating the fracture and placing proppant into the fracture. Fracturing as discussed here is distinct from drilling, casing and cementing operations. Effective hydraulic fracturing relies on the ability to isolate a section of the wellbore so that the injection only increases pressure in that section and the hydraulic fracture initiates from that section. A cemented steel casing string is one common method to achieve this isolation. The cemented casing string also provides a seal that prevents movement of fluids either into and out of the well or up and down the well outside of the casing.

To produce the water and gas from the coal seam, holes are introduced that penetrate the casing, cement and a short distance into the coal. These holes are typically created using perforating guns that consist of a string of shaped explosive charges that, when set off, shoot an explosively generated jet through the steel, cement and rock to a distance of 200 to 400 mm into the coal. Alternatively, a high pressure water and sand slurry can be directed at the casing to cut a hole or slot through the casing and into the coal. Hydraulic fracturing is then done by isolating the perforated section, typically by installing a plug inside the casing that presses against the casing to hold itself in place. Pumping fluid down the well then pressurises the section perforated. The fluid pressure increases until the in situ stress and strength of the rock are exceeded, resulting in formation of a fracture. This fracture is extended as a hydraulic fracture by continuing to pump the fracturing fluid into it as it grows in size into the reservoir. The rate of growth of the fracture depends on the fluid injection rate and on its overall shape and on a number of other rock property and fluid details. The rate of fracture growth decreases with time and, typically after 15 to 20 minutes, growth has slowed to a few metres per minute. Hydraulic fracture treatments in coal would typically create fractures extending to between 100 and 300 m, but smaller and larger fractures can be formed depending on the injection rates, seam thickness, fracturing fluid type and volume, and other details of the coal, surrounding rock, in situ stress and treatment execution. Volumes used per fracture treatment range from a few hundred litres for test fractures up to approximately one million litres. Average treatments might be approximately 250,000 litres in volume. Injection pressures depend on the depth of the interval being fractured and typically range from 10 MPa to 40 MPa. Average pressures might be 25 MPa. Both the volume injected and the pressure response observed are dependent on details of the site and the stimulation design.

1.2 Selecting wells for fracture stimulation

Permeability and stress are the two main technical factors that must be considered when an operator is deciding whether to use hydraulic fracture stimulation in a well. Permeability, which determines how easily fluid flows through rock, is variable in all basins in Australia and across the world. In general, Australian basins on the east coast are subject to more compressive stress than US basins, which means coal may be less permeable at the same depth and hydraulic fractures will be more contained to the seam. But there are sites where this does not hold so each site has to be characterised to determine permeability and stress and potential for hydraulic fracture height growth out of the targeted seam.

Seams in Australia and in NSW occur over a range of depths, from near the surface and even outcropping to deeper than 2,000 m. The seams located less than approximately 200 m from the surface tend to be of lower gas content and are not typically targeted for coal seam gas extraction. Likewise, seams deeper than 1,000 m are typically less attractive because drilling costs are higher and the seams tend to be of lower permeability, which makes extraction of the gas more difficult and more expensive.

2 Current Practice for CSG Stimulation

Hydraulic fracture stimulation of CSG wells in Australia is done using several treatment designs. The fluids used range from water that has been treated to remove bacteria to gelled fluids that are water based with additives used to increase the fluid viscosity. Bacteria is removed because they metabolise gel additives in fracturing fluid which degrades the fluids performance. The introduction of bacteria into the coal seam may also result in damage to the reservoir. Additives such as guar are used to make gelled fluids, which produce fluids that are more viscous than water and therefore transport the proppant more efficiently. The most common treatments used in Australia are slick water fracs with sand proppant and hybrid fracs that start with slick water and use crosslinked gel in the last part of the treatment in order to place more sand proppant in the fracture. Slick water consists primarily of water, a bactericide, and an additive to reduce fluid friction while pumping. Crosslinked gels are made by adding a crosslinker to the mix water that promotes the interlinking of the guar or other polymer molecules in the fluid to form a more viscous fluid system (Ely, 1989). One common crosslinker additive is boric acid. Occasionally, a treatment is carried out using a foam fluid in order to minimise the exposure of a water sensitive coal to water. Details of these fluid systems can be found at http://fracfocus.org/welcome and are described in a recent SPE paper by King (2012).

2.1 Other uses of hydraulic fracturing

In addition to its use in stimulating gas and oil wells, hydraulic fracturing is used to stimulate water wells, although its use for this purpose is uncommon in Australia. Hydraulic fracturing has been used in NSW since 1997 to weaken rock in coal and metal mining operations (van As and Jeffrey, 2000; Mills et al., 2000). This type of work is usually done before mining in order to precondition the rock so that it will fail uniformly when mining occurs. Fracturing for preconditioning is currently being used in NSW at two mines and several other mines are considering using it. Preconditioning involves pumping small volumes (typically 10,000 litres but up to 20,000 litres) to create fractures in the rock. Fracturing in mines is carried out inside the mine, in or near the ore body or coal seam, and all fluids are captured by the mine water collection system.

Deep wells are used with hydraulic fracturing to dispose of waste material, with the most common application being the disposal produced liquid waste or drilling waste (Abou-Sayed et al., 1994).

Hydraulic fracturing has been tested, with positive results, to stimulate holes drilled from underground into coal seams that are used to drain gas before mining (Jeffrey and Boucher, 2004). It is not currently being used for this purpose in Australia.

Small hydraulic fractures are used to measure in situ stress and this technology, which typically involves injecting 10 to 100 litres of water, has been used for more than 40 years across Australia (Enever et al., 2000).

3 The Decision to Fracture or Not

The reservoir permeability is a primary factor that influences the decision as to whether a particular well or collection of wells should be stimulated by hydraulic fracturing. Other factors that are considered include the seam thickness, stress contrasts between the seam and surrounding rock layers, and the geological and structural setting of the well. Early in development of a new basin, the higher permeability zones are sought. As these are found and drilled out, often without requiring any stimulation to produce the gas, the parts of the basin with lower permeability coal are developed with most of the wells requiring stimulation. An example of this on a large scale is provided by gas production in the USA from coal, shale and conventional gas reservoir rocks. Because onshore gas production has been underway for a considerable time, the high permeability targets are under production or depleted. Therefore, up to 80 percent of new gas wells, which are in lower permeability reservoir rock, in the US will require stimulation by hydraulic fracturing (American Petroleum Institute web page, 2012). It can be expected that as coal seam gas is developed in NSW, the number of wells requiring stimulation to be productive will increase.

This discussion assumes that an assessment of gas content and composition has been made and has indicated there is sufficient methane in the seam to warrant development and production.

3.1 Seam thickness and stress

Stress is defined as force per unit area that is acting in the rock. For example if a force of 1 million Newtons is applied to a surface area of 1 square metre, a stress of one megaPascal (MPa) is generated. When a layered rock is compressed, the stiffer layers will carry more of the load and will contain higher stresses. Thus, the stiffer sandstone layers will have higher stress in them than the softer coal when they are compressed by tectonic forces (Enever et al., 2000).

If an individual coal seam is thin and would not contain enough gas to be a viable target for production by itself, hydraulic fracturing can be used to fracture stimulate a number of seams with one treatment. Whether or not a number of seams can be successfully fractured is a function of the seam thickness, the thickness of the interburden rock between them and the stress acting in the seams and in the interburden rocks. Site characterisation must be undertaken to determine if this approach is likely to work or not.

For this approach to work, the hydraulic fracture must grow with a vertical orientation and extend through the coal seams and the rock layers between the coals. This in turn requires that the minimum stress in the rock is about the same as the minimum stress in the coal and that both of these minimum stresses are horizontal. Under these stress conditions, which exist in some basins in Australia, a vertical hydraulic fracture can be grown through a number of seams and then by using a thicker gel fluid to transport the proppant, the fracture plane can be propped sufficiently to make it conductive over its height allowing water and gas to be produced from all of the seams. Reliably growing and propping such a fracture can be a challenge because the fracture may be diverted to become horizontal at the coal-rock interface and the proppant tends to settle vertically through the fluid so that the lower part of the fracture channel is well propped and highly conductive at the expense of propping and maintaining conductivity in the upper part. Predicting the potential for vertical height growth of the fracture is part of the design phase. In addition, microseismic and tiltmeter monitoring are often used for initial wells and for pilot sites to improve understanding of the reservoir response to fracturing and to obtain more information about the fracture growth. Then, this understanding is included into the models for use in designing and carrying out the more routine stimulation work associated with developing a well field.

3.2 Hydraulic fracture modelling

A number of models are commercially available that have been developed for use in designing a hydraulic fracture treatment. In addition, some service companies have in-house proprietary design models and some consultants use their own in-house models. Researchers typically use commercial models and develop their own in-house models. The models account for the physical processes that occur as a fracture grows into the reservoir rock. The models can be used to predict the growth of the fracture in length and height as the injection is carried out. Conditions that either prevent or allow the fracture to grow vertically are included in the model so that an overall prediction of the height and length of a vertical fracture is obtained. The transport and settling of proppant as it is carried by the fracturing fluid in the fracture is also considered. The fracturing model may even be coupled to a reservoir model to obtain more accurate predictions of the fluid lost from the fracture into the reservoir. The propped fracture channel that results from the treatment, as obtained from the hydraulic fracture modelling, is then transferred to a reservoir model, which allows predictions to be made of the stimulated gas and water flow from the coal reservoir during production. Research fracture models typically consider some aspects of the process in detail. For example, the detail of the deformation and stress changes that occur as a vertical fracture grows from a coal seam into a bounding stiffer rock layer is a problem that would be typically studied using a more specialised model in a research setting.

The modelling of hydraulic fracture growth in coal and in the layered rock around the coal is complicated by the naturally fractured nature of the coal, which leads to non-linear fluid loss, and by fracture branching and offsetting at natural fractures and layer interfaces, which leads to non-planar fracture growth (Jeffrey and Zhang, 2008). Predicting fracture growth in coal is therefore difficult and must rely on careful site characterisation and remote monitoring data from pilot studies to guide the engineer in calibrating the model. Once a model has been calibrated, it can be used for routine design, but design predictions should be continuously compared with measured data from the treatments as they are carried out.

3.3 Fracture stimulation of individual seams

In situ stresses in the subsurface rocks along the east coast of Australia are affected by plate tectonics, which has acted to impart an east-west to northeast-southwest compression. The compression of a layered rock system will increase the stress in the stiffer rock layers (such as the siltstones and sandstones) compared to the stress in the softer coal layers. Hydraulic fractures that are initiated in the coal will then tend to be contained to the coal because the higher stress in the rock layers above and below the coal act to limit the fracture growth in these rocks. The horizontal stress is often high enough in the rocks around the coal seam that if the hydraulic fracture does grow into them it will reorient to become horizontal (Enever et al., 2000; Jeffrey and Zhang, 2008). The coal seams then need to be fracture stimulated one by one.

Target seams are selected based on their thickness and gas content. The decision to stimulate them or not is made based on their permeability.

Permeability is the property of the rock that determines how easily a fluid will flow through the rock. If all other parameters are fixed, then doubling the permeability will produce double the rate of fluid flow through a rock. Permeability, as used by oil and gas engineers, is a property of the rock and is expressed in units of md (millidarcy) or metres squared. In groundwater studies, the fluid viscosity is included into what is called permeability and the units used are centimetres/second or metres/day for example. Groundwater permeability when expressed with units of velocity is a property of both the rock and of the fluid flowing. Average beach sand might have a permeability of 100 Darcy while concrete permeability is approximately 0.01 md, where 1 Darcy is equal to 1,000 md.

As stated above, permeability as defined and used in the oil and gas and coal seam methane industries is a property of the rock. It does not depend on the fluid or saturation. But, relative permeability depends on saturation. Relative permeability is the ratio of the apparent permeability at the existing saturation to the permeability at 100% saturation. Flow of water through the rock then depends on how much gas is present and vice versa. Permeability of coal is controlled by the natural fractures in the coal. This contrasts with permeability in a sand or sandstone rock where the flow occurs through the pore space between the grains rather than through fractures. A naturally fractured rock material, such as coal, will have a permeability that is sensitive to the confining stress acting on it. Higher stress acts to close the fractures and reduce the permeability. Furthermore, if the natural fractures are filled with minerals, such as calcite, the permeability is reduced.

Coal seams that have permeabilities above 20 or 30 md do not usually require stimulation. These higher permeability coals can be produced by drilling surface to in-seam wells or vertical wells. Coals below 0.1 md are not economic even after fracturing from a vertical well completion. The target seams for hydraulic fracture stimulation typically have permeabilities that range between 1 and 20 md. Seams that are less permeable than 1 md might be produced at economic rates by drilling horizontal wells and placing multiple fractures along the well, but this technology has yet to be proven in Australia. Seams with permeabilities above 20 md are sometimes fractured because the economics of the well are improved by the stimulation.

3.4 Carrying out stimulations

Hydraulic fracturing can be and is used by companies of different size. The fracture stimulation is almost always carried out by a service company and the cost of the service would be similar for the same type of treatment, regardless of the size of the company. The three service companies offering hydraulic fracturing in Australia are Halliburton, Schlumberger, and Baker Hughes. Much like drilling companies, they provide a service to any company contracting them.

The service company can design the treatment and to carry it out, so operating company in-house design expertise is not necessarily needed. Larger companies may be able to negotiate a lower stimulation cost by offering a larger number of wells for stimulation at one time. But such considerations are unlikely to be the deciding issue dictating whether a well is stimulated or not. The cost associated with fracture stimulations are typically reduced as more wells apply the technology and service companies compete with one another for work. Small companies may choose to fracture a vertical well first because it is cheaper overall and provides them with a well or wells that are producing. Pilot wells are also usually completed as vertical wells and may need fracturing to test the coal seam productivity. Horizontal wells cost approximately $1 to 2 million to drill and complete, without fracturing. A vertical fractured well might cost $400,000 to $800,000 depending on the number of seams treated. It is likely that horizontal wells will be fracture stimulated in the future, just like shale gas wells are now, which will allow recovery of gas resources from lower permeability coals.

4 Use of Fracturing During Different Phases of CSG Operations

Hydraulic fracturing can be used during nearly all phased of CSG operations.

Exploration and Characterisation: Hydraulic fracture may be applied during exploration in the form of in situ stress measurements, which are small fractures formed by injection of 10 to 100 litres of water or as DFITs (Diagnostic Fracture Injection Tests). DFITs are sometimes used in low permeability coal to obtain seam permeability and reservoir pressure. These tests then replace conventional well testing. A DFIT is a hydraulic fracture treatment that involves injecting a small volume of water, perhaps 500 to 2000 litres, and then monitoring the pressure decline after the injection stops. Analysis of this falloff data is used to extract seam permeability and reservoir pressure.

Drilling: During drilling, after a casing string is cemented into the well, it is common to drill a few metres of new hole and then pressurise this open hole to test the integrity of the cement job. The borehole is pressurised until a fracture forms at the wellbore wall. These tests are called Leakoff Tests (LOT) in the drilling industry and can also be used to estimate the in situ stress. For stress measurements, the injection period is extended and the pressure decline after injection is monitored for an extended period. Such extended leakoff tests (ELOT) might involve injecting a few thousand litres of drilling fluid into the rock to form the fracture.

Pilot Wells: In new areas, it is common to drill 3 to 5 pilot wells near one another and, if the seam permeability requires it, to hydraulically fracture the seams in each well and produce the wells together as a pilot test. Fracture treatment designs are often varied between pilots to determine an optimal stimulation for the new area and several pilots are usually set up across a new area to test different structural settings and different seams. Treatments in pilot wells are done at full scale and typically involve injection of from 100,000 to 2,000,000 Litres of fracturing fluid per well. Treatments would normally be carried out in several different coal seams in each well.

Production: Once a field is being developed for production, a number of wells will be drilled and completed. By scheduling the hydraulic fracturing of groups of these wells in one campaign, the cost per treatment can be reduced (by negotiation with the service company).

Producing Field: It is common for wells to require work over, which typically involves removing the pump from the well, cleaning the wellbore out (coal and proppant sand may enter the well through the perforations and collect below the pump), repairing the pump if required and re-installing it. Some wells may be re-fractured at this time. Re-fracturing a well involves essentially the same operation as the original fracture stimulation and quite often results in significant production increase.

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6 Appendix A – Notes on history of hydraulic fracturing applied to CSM in Australia

Compiled by Rob Jeffrey, CSIRO Earth Science and Resource Engineering
January 2012

1969, First Fracture Treatment in Australia: The Moomba-8 well, in the Cooper Basin of SA was stimulated by hydraulic fracturing in September 1969 (McGowen et al., 2007). Another well is believed to have been stimulated in the same area in 1968, but this has not been verified. This was not a coal seam methane stimulation.

1976, First CSM Exploration Wells: The Carra-1 and Kinma-1 wells were drilled for coal seam methane exploration and Moura-1 and Shotover-1, which were existing petroleum exploration wells, were recompleted to test coal seams in Queensland (GA, 2001).

1980-81, Gas Drainage. Four vertical wells at Leichhardt Colliery (S of Blackwater, Qld) and four vertical wells at Appin (near Wollongong, NSW) were hydraulically fractured in 1980 and 1981 by BHP (Stewart and Barro, 1982). The objective of this work was to test vertical wells as a means of draining gas from the coal before mining. Nitrogen foam fracs, with sand proppant, were used in all cases. Halliburton provided the fracturing services with equipment sourced from their existing fleet used for conventional oil and gas fracturing work in Australia (Stewart and Barro, 1982).

1989, Gas Drainage. A single vertical well was fracture stimulated in March 1989 at Central Colliery in Queensland (Seamgas report, 1989). The fracture was mined and mapped and is described by Jeffrey et al. (1992). A borate crosslinked fluid was used to place sand proppant. Dowell Schlumberger pumped the treatment using equipment already in Australia (Jeffrey et al., 1992).

1986-92, Early Coal Seam Methane. Median Oil N.L. obtained the Authority to Prospect lease 364P which was acquired by CB Resources Pty Ltd. They developed the pilot Broadmeadow Field north of Moranbah and drilled and fracture stimulated 8 wells for the purpose of producing coal seam methane (ICF Lewin report, 1988). CB Resources became North Queensland Energy (NQE) which carried out a number of exploration and pilot production trials in Queensland into the early 1990s. NQE with Capricorn Coal funded small scale fracturing trials with CSIRO at German Creek.

1980s, AGL. AGL explored for CSM in the Sydney Basin in the 1980s with production by shaft sinking and drilling of horizontal holes from the bottom of the shaft with limited success. Pacific Power took several leases in the Sydney Basin and began exploration activities in the late 1980s. Pacific Power funded CSIRO to carry out small-scale hydraulic fracturing experiments at Munmorah and Dartbrook (with Dartbrook). Amoco took over the AGL leases in the early 1990s and carried out several pilot trials involving hydraulic fracturing of vertical wells (Bocking and Weber, 1993).

Feb. 1996: First commercial production (sold into a pipeline) from holes drilled into an open cut highwall at Moura, Qld. These horizontal wells were not fracture stimulated (GA, 2001)

Dec. 1996: First commercial production from vertical CSM hydraulically fractured well fields in the Dawson Valley (GA, 2001).

1996 – 2006. Increasing commercial Production. The Geoscience Australia URL below gives a list of first commercial production by a number of companies. Commercial production started in 1996 at Dawson Valley using hydraulic fracturing (now owned by Westside Corp).Other commercial production dates are 1998 some fracturing (Santos, Fairview Field), 2000 (Origin, Peat Field), 2001 using hydraulic fracturing

(AGL, Camden), 2004 SIS wells (Arrow, Moranbah), and 2006 under reaming of initial wells but now fracturing (QGC, Berwyndale).

In 1998 production of CSM was 9 million cubic feet per day and by 2001 this had increased to 22 million cfd. By 2002 this had increased further to 62 million cfd which met approximately 25% of Queensland's natural gas demand at that time (GA, 2001).

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