Reference document: Hydraulic Fracturing

- Hydraulic fracturing (fraccing) is used to enhance oil and gas flow in rocks with very low natural permeability.
- Hydraulic fracturing practices have been developed over more than 65 years in millions of wells around the world.
- Engineering a hydraulic fracturing operation requires detailed designs that use specialised geological data.
- Fraccing operations are carefully monitored to ensure alignment with the design.
- Low-concentration chemicals are used to make the frac more efficient.
- Frac fluid management minimises environmental impact.
- Diagnostic techniques are used to ensure that fracs are executed to plan and to identify opportunities for improvements.

1. Enhancing oil and gas flows in rocks

1.1 Background

Permeability is a measure of the interconnectivity between pores within a rock. It determines how well oil, gas or fluids to flow through the rock. High permeability makes it easier to extract oil or gas. Some rocks have very low permeability, which means that oil or gas held in these rocks will not flow readily to any wells drilled to develop the resource.

Permeability can be artificially increased by applying hydraulic fracturing (or "fraccing") to the reservoir. Fraccing expands the natural fractures in the rock, creating larger or new pathways to the well bore. These fractures can be created in two ways, either by pumping chemicals like acids down the well (called a chemical or acid frac), or simply using high pressure to form the cracks. These high-pressure fracs are called 'hydraulic fracs' because it hydraulic pressure, rather than chemicals, causes the cracks. Almost all fraccing in Australia is hydraulic.

Because Australia has some of the highest permeability coals in the world, seven out of eight coal seam gas wells do not require fraccing[1]. However, all tight sandstone and shale gas wells are fracced, since these rock types generally have very low permeability.

Hydraulic fracturing also enhances the oil and gas recovered from individual wells by increasing the area of drainage. This reduces the number of wells (and the associated surface footprint) needed in a development area.

As the world's more easily developed petroleum reserves deplete, companies must exploit less permeable rocks. Typically these are very tightly compacted sandstone, shale or coal. These reservoirs are often referred to as 'unconventional' because they require special production operations beyond the conventional operating practices. However, the actual oil and gas in these rocks is exactly the same as that in any other petroleum reservoirs. At the surface, there is no material difference between an unconventional or conventional petroleum well. Below the surface, technology is applied to coax the oil or gas to move towards the wells, and eventually to the surface for processing. About half of today's gas reserves are found in unconventional reservoirs.

[1] http://www.appea.com.au/industry-in-depth/industry-statistics/

1.2 Hydraulic fracturing history and research

The first commercial hydraulic fracturing was completed in the United States in 1949. Since then, more than two million fracs have been completed worldwide. Australia's first frac was undertaken in the early 1960s.

In its most basic form, a frac applies water at very high pressure at specifically targeted positions in a rock section to generate a contained hydraulic fracture and stimulate production from a reservoir. [2]

Hydraulic fracturing is well understood. It has been thoroughly researched – many universities, consortia, and public and private scientific organisations have studied fraccing. More than 10,000 references have been published on rock mechanics, lab research, modelling, case studies, diagnostics, design, execution, and evaluation of hydraulic fractures in many types of rocks.[3]

2. Hydraulic fracturing requires detailed engineering and design

2.1 Hydraulic fracturing basics

Creating the fractures: Hydraulic fracturing is the process of pumping water-based fluids down a well bore at high pressures and into specific, isolated sections of rock under carefully designed conditions. These fractures are usually a few millimetres wide, and can extend to more hundred meters from the well bore[4].

Keeping the fractures open: To hold the fractures open after the pumping has stopped, material such as sand (called proppant) is added to prop the fractures open against the pressure of the rocks. Some chemicals are added to neutralise any acidity; increase viscosity so the fluid carries more sand to the ends of the fractures; and to help maximise the flow back to the borehole.

Cleaning up the fractures: When the fracture is set, fluid is allowed to flow towards the well bore to clean up the fractures and establish the paths for the petroleum to travel to the bore hole.

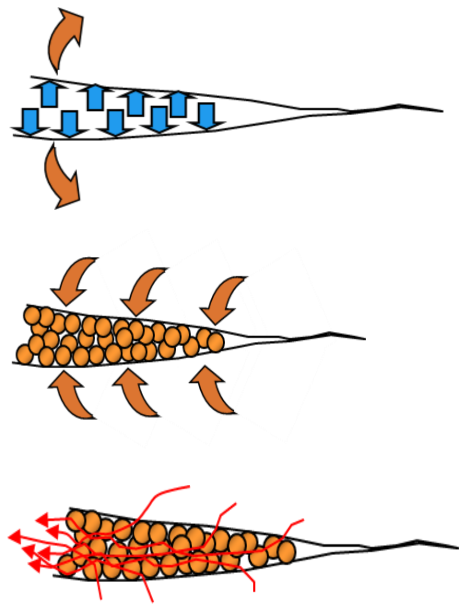


Fig 1: Frac Basics

2.2 Design inputs for hydraulic fracturing

Borehole measurements (or logs) and geologic models are used to assess the rock properties and select the appropriate fracture treatment based on the desired fracture containment, length and growth. The team measures the stiffness or elasticity of the rock at different depths, and the underground forces acting on each layer (known as 'in situ stresses').[5]

Log-derived properties are used to identify the layer that has the least pressure. This will be the fracture initiation layer. ***See overleaf.***

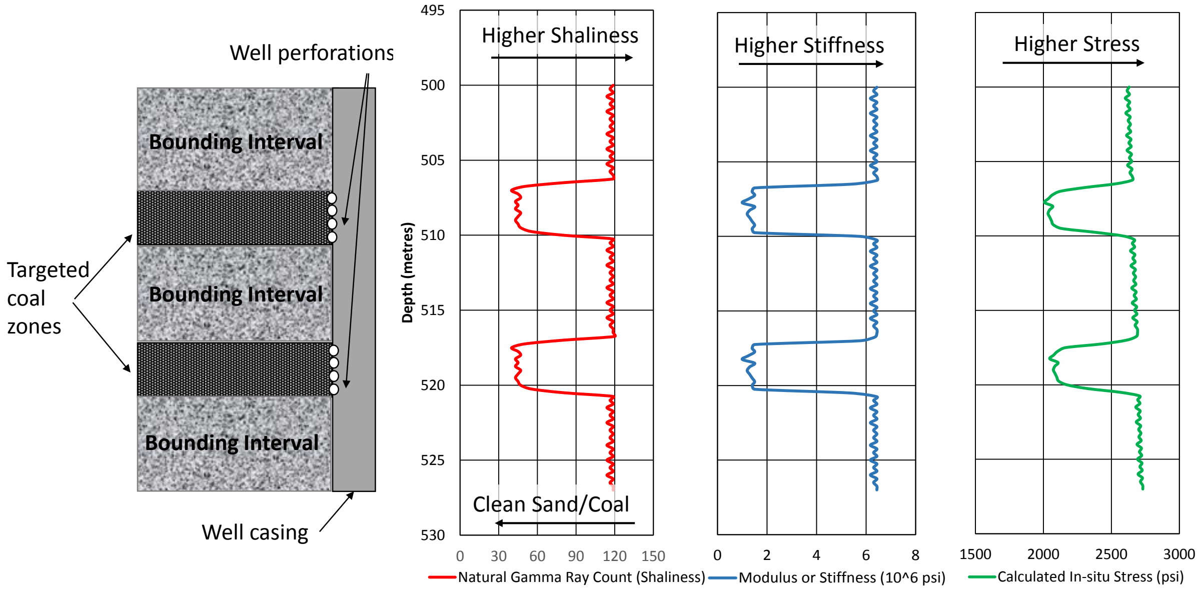
[2] http://www.fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process

[3] http://www.onepetro.org

[4] http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0005/56849/Report_NSW_OCSE_May2012_FracturingCoal.pdf

[5] Nolte, K.G. and Smith M.B., Interpretation of Fracturing Pressures, paper SPE 8297-PA, 1981 at http://www.onepetro.org

Fig 2: Representation of target interval selection for perforating based on log parameters such as amount of shale in the rocks (shaliness), modulus or stiffness, and in situ stress values.[6]



2.3 The hydraulic fracturing engineering design process

Based on decades of process optimisation, multi-disciplinary teams of petroleum professionals use several tools and processes to design a frac and guide its successful implementation. The frac design process includes several steps:

Developing geological models:

- A field geological and geomechanical model is based on geological data and previous wells.
- The geologist and petrophysicist update the models using measurements obtained when drilling the well to make a stress or stiffness log (Fig 2).

Testing well integrity:

- Well pressure integrity is assured by both the drilling and completion engineers pressure testing the casing and well head valves and, where applicable, running cement bond logs.
- Fracturing fluids are tested with the drilling cuttings or cores to achieve compatibility with the rock and protect the well using the minimum required additives.[7]

Detailed planning:

- Based on the logs the lowest stressed (least pressured) section of rock in the total section is targeted for stimulation. It is selected as the fracture start or initiation point and used as the basis of calibrating a hydraulic fracturing model, a process well known since the early 1980s.[8]
- The geologist, frac engineer and reservoir engineer determine a diagnostics plan that lets them evaluate the fracture execution, and optimise future frac operations.
- The frac and completion engineers prepare a comprehensive operational plan that includes safety and environmental management plans and contingencies.

Since the frac treatment is often the most expensive operation performed on a well, most companies have developed detailed processes and workflows to assure the optimal frac design, execution and evaluation plans are well conceived and verifiable by field observations or diagnostics.

[6] Coates, G.R. and Denoo S.A., Log Derived Mechanical Properties And Rock Stress, SPWLA paper 1980-U.
[7] Crane, et al: "Fracturing Fluid Testing for Design Purposes and Regulatory Oversight in a Shale Gas Project," SPE 167107, 2013.
[8] http://www.slb.com/~/media/Files/resources/oilfield_review/ors13/sum13/04_stim_design.pdf

3. A frac's execution is carefully monitored to ensure alignment with the design

Once the frac design has been finalised, the completion and frac engineer manage the operational and technical execution on-site (Fig: 4) and:

- perform any additional pressure testing and verifications of wellhead integrity;
- verify the frac model by performing initial injections in the desired rock section commonly known as a diagnostic fracture injection tests (DFIT) or mini-fracs, and comparing (or 'history-matching') those results to the frac model predictions (Fig: 5);[9]
- adjust the frac design based on the mini-fracs, if history-matched results vary greatly from the model predictions; and
- execute the hydraulic fracture treatment using the frac model history-match and collected on-site diagnostics data.

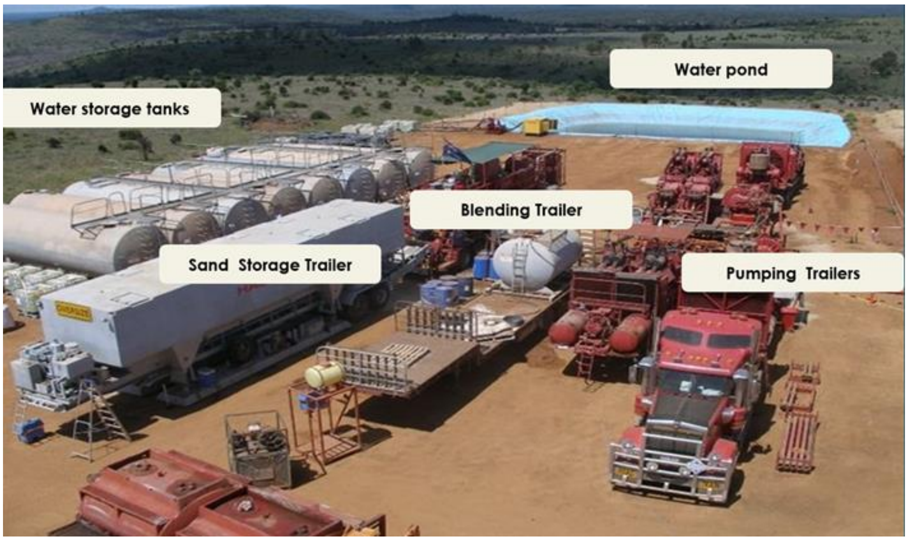
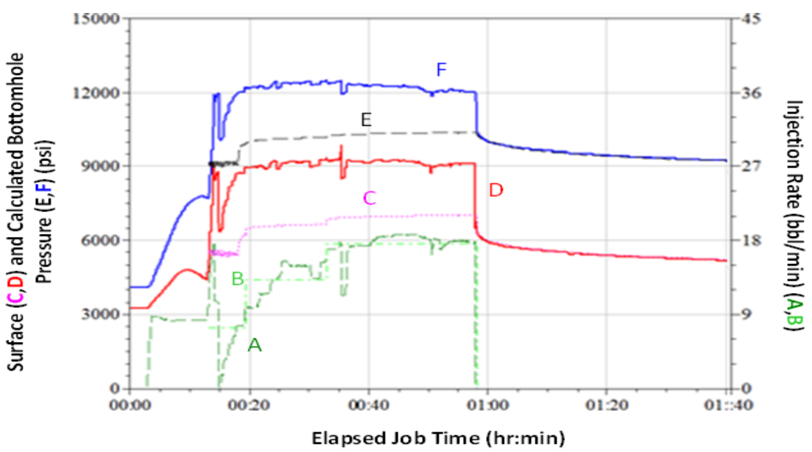


Fig 3: Typical On-site Hydraulic Fracturing Operation

Source: QGC

Fig 4: Australian example of correlated, mini-frac, injection pressure history-match to a planar 3D hydraulic fracturing model (after Johnson and Greenstreet)[10]



A. Actual injection rate (bbl/min)
B. Model input injection rate (bbl/min)
C. Model Predicted Surface Pressure (psi)
D. Observed Surface Pressure (psi)
E. Model Predicted Downhole Pressure (psi)
F. Surface Calculated Downhole Pressure (psi)

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[9] Johnson, et al. "Utilizing Current Technologies to Understand Permeability, Stress Azimuths and Magnitudes and their Impact on Hydraulic Fracturing Success in a Coal Seam Gas Reservoir," SPE 133066, 2010.

[10] Johnson, R.L. Jr. and Greenstreet, C.W.. "Managing Uncertainty Related to Hydraulic Fracturing Modeling in Complex Stress Environments with Pressure-Dependent Leakoff," SPE 84492, 2003.

4. Low concentration chemicals are used to make the frac more efficient [11]

- **Water (>90%):** Water is the base fluid used to transmit the pressure from the pumps at the surface down to the rocks and efficiently open the cracks.
- **Gelling agent (<1%):** It is difficult to get water to carry all the sand right to the end of the fractures as the sand is about twice the density of the water. To enhance carrying capability, a 'gelling agent' is used to increase the viscosity. Guar gum (from guar beans) and cellulose gums (from plant fibres) are the most common gelling agents.
- **Breakers (<1%):** Once the gelling agent has done its job carrying the proppant, it must be removed from the fractures or it will clog the cracks. Oxidizing or enzyme agents are injected to 'break down' the gelling agent's viscosity by degrading the gum's polymers. This allows the fluid to flow back to the well where most of it is brought back to surface for treatment or recycling.
- **Friction reducers (<1%):** Stable polyacrylamides are used to decrease fluid friction. This 'slickening' reduces the horsepower needed to pump the frac.
- **Surfactants (<1%):** These are added to help fluid recovery after the frac by reducing the surface tension of water. In liquid detergents and soaps surfactants are used to shift oil and grease.
- **Biocides (<1%):** These minimise biological contamination and bacterial infestation in the well, which could corrode the steel casing. The most common biocide, chlorine, is used in swimming pools and drinking water. Others are used in large air-conditioning systems or cooling towers.

Component	Volume	Purpose	Other uses
Water	>90%	Applies pressure to the rocks, and carries proppant into the fractures	Groundwater, surface water, or recycled water
Clay management (e.g. sodium and potassium salts)	< 1%	Minimises clay swelling or fluid interaction with the surrounding rock	Swimming pool salt, food additives, soil treatments
Gelling agents (e.g. guar or cellulose gums)	< 1%	Increases viscosity of fluid to carry more sand into the fractures	Cosmetics, ice cream, food thickeners, personal products
Breakers	< 1%	Breaks down the gelling agents after the proppant is carried into the rock fractures, enhancing gas flow and frac fluid recovery	Hair bleach, food additive, washing powder, enzyme products
Friction reducer	< 1%	Reduces friction of frac fluid, which decreases required pumping horsepower	Cosmetics, hair gel, drinking water and waste water treatments
Surfactants (eg alcohols, turpenes)	< 1%	Reduces fluid surface tension to aid fluid recovery and prevent emulsions forming	Soaps, detergents, household cleaners
Biocides	< 1%	Inhibits bacteria that could contaminate the frac fluid, rock or wellbore	Disinfectants, bleach, swimming pool chemicals
Corrosion and scale inhibitors	< 1%	Reduces corrosion of steel casing and the build-up of mineral precipitates in the well	Gelatine, swimming pool scale preventatives, instant coffee, detergents
Cross linkers (eg borate salts)	<1%	Links guar or cellulose polymers to enhance viscosity	Borax, laundry detergents, cleaners
Other stabilisers, buffers and acids (e.g. hydrochloric acid, sodium bicarbonate, acetic acid, sodium hydroxide)	< 1%	Maintains frac fluid stability by managing pH, iron control and reducing chlorine and other free radicals that could affect crosslinking of the polymers	Household cleaners, vinegar, baking soda, swimming pool pH and chlorine adjustors, aquarium chlorine remover

[11] http://fracfocus.org/sites/default/files/publications/hydraulic_fracturing_101.pdf

5. Frac fluid management minimises environmental impact

The volume of frac fluid used varies according to the rock being fractured, the depth of the well, and total frac stages per well.

A typical CSG well frac uses 0.1 to 3 megalitres (ML) of fluid, as coals are shallow and fracture easily. Shale is deeper and harder to frac; it often requires a multistage shale frac and 5 to 40ML of fluid per well.[12] By comparison, an Olympic swimming pool holds 2.5ML.

After the frac job, the frac fluid and any loose proppant in the wellbore flow back to the surface for storage in tanks or lined ponds. Breakers added to the frac fluid reduce the polymers to smaller fragments or simple sugars and sunlight generally degrades biocides to an inactive sulphate salt.

About 40-60% of the injected volume of frac fluid can be recovered. This is tested and can be filtered or treated. It is then:

- reused in other frac treatments;
- mixed and treated with other production fluids; or
- allowed to evaporate with any solids disposed of in an appropriate disposal facility.

All operators plan frac fluid management as part of their environmental management plans. These plans are based on pre-frac tests, the likely interaction between the fraccing fluid and the rock, and the resulting fluid that will return to the surface after intermixing with rock formation fluids.

Operators are also adopting new technologies that optimise water management and frac fluids recycling to reduce overall water usage and environmental impact.[13]

6. Diagnostic techniques optimise fracs and identify opportunities for improvements

Computerised hydraulic fracturing models and pressure observations can help optimise fracs. New technologies such as short-lived radioactive tracers can also be used in the modelling process to better understand fracture height and length.

In the mid-1980s technological advances, such as surface and downhole deformation tiltmeters (or very sensitive inclinometer or level gauge) and microseismic monitoring, enabled development of the advanced 3D models the industry now uses.

[12] http://www.gisera.org.au/publications/factsheets/shale-gas-australia.pdf

[13] Fedotov, et al. "Water Management Approach for Shale Operations in North America," SPE 167057, 2013.

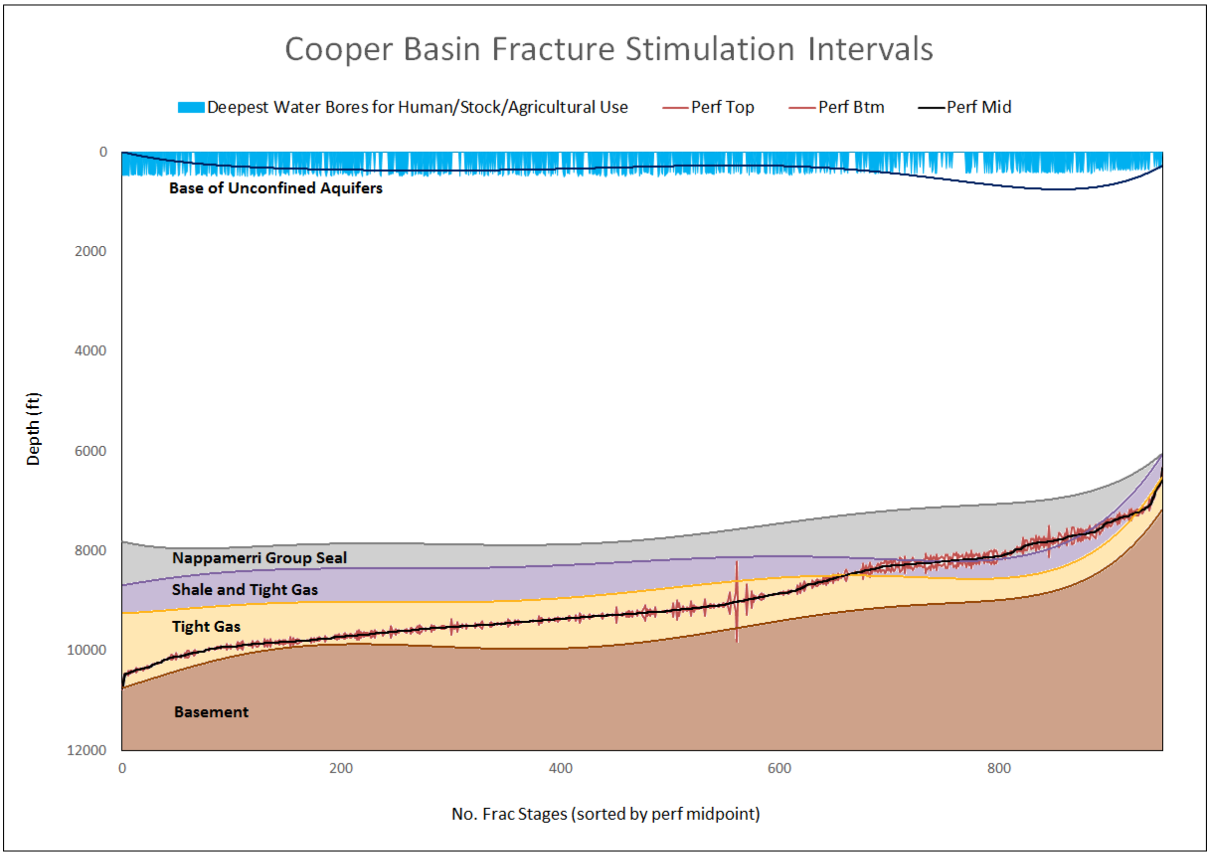
7. Hydraulic fracturing and aquifers

Typically, hundreds of metres of rock separate a fracture stimulation from any sensitive aquifers, such as those used for domestic or agricultural purposes.

In the case of the Cooper Basin in South Australia, the area affected by a fracture treatment (as noted by the trend line of depth of stage from all treatment stages) is far below the depth of any known aquifer at the same location (Fig. 5).

The Australian Council of Learned Academics (ACOLA) has published a summary review of the risks associated with fracture stimulation and concluded that there is no evidence of hydraulic fracturing fluids moving up in the earth from a fraccing operation to a surface aquifer.

Fig 5: Separation of fracture stimulation in the Cooper Basin from fresh water supplies. Based on 716 fracture stimulated wells to end of August 2014.[14]



8. Summary

Hydraulic fracture design, execution and evaluation began in 1949 as a process of empirical experimentation. By the mid-1980s it was a well-understood science that used the latest computational modelling tools and sensitive geotechnical diagnostics.[15]

Highly trained fracturing engineers specialise in this multi-disciplined process to assure that the most costly operation in a well's life targets only the desired section of the rock that can lead to the highest well productivity. For years, the industry has gathered valuable diagnostic data in a quest to better design, execute, and evaluate hydraulic fracture treatments.

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[14] Department of State Development, South Australia, 2014

[15] King, George E: "Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells," SPE 152596, http://fracfocus.org/sites/default/files/publications/hydraulic_fracturing_101.pdf, 2012.