



**Coal Bed Methane Geo-mechanics - Field Experiences & Developing a Computer Application**

*Pushpa Sharma\*, Shivam Saxena, Amritansh Tripathi, Abhilasha Bhatnagar, Divya Singhal, Ishita Mathur;  
University of Petroleum & Energy Studies, Dehradun*

pushpa.sharma@ddn.upes.ac.in

**Keywords**

Mechanics, Extraction, Perforation, Fracturing

**Summary**

Extraction of CBM involves perforation and fracturing as key processes which critically influence the gas production. Deviated wells, complex completions, and multiple coal seams are factors that make CBM production a challenging task. Various problems are encountered at each stage of the well life before start of commercial production.

Field experiences in Raniganj Area in West Bengal, India have been used for this study. Various cases have been analyzed by the authors to arrive at significant factors in different scenarios like rock mechanics and phasing misalignment in perforation. Study has been done on field data to arrive at conclusions on root cause of such issues and justify the same.

A computer application for windows has been developed by the authors to summarize the technical calculations used in the study which involves geo-mechanics, perforation and fracturing. Lessons learnt from the field experience gained by the authors can be used as examples in other similar cases for better application of time, money and effort.

**Introduction**

The mechanical properties of the coal determine the reaction of the rock to imposed stresses of fracturing. Elastic properties determine the effect of imposed or in-situ stresses on existing natural fractures or previously created hydraulic fractures, directly affecting the permeability of the rock system. In coal bed reservoirs, rock mechanical properties and related stresses are of great concern.

$E = \sigma / \epsilon$   
 E = Young's Modulus (psi)  
 $\sigma$  = Stress (psi)

$\epsilon$  = Strain

Young's modulus is important in establishing the width of the fracture in the coal, and it plays a minor role in limiting fracture height. Maximum width, w, of a fracture near the wellbore is inversely proportional to the fourth power of Young's modulus as in the fracturing model of Geertsma and de Klerk.

Soft, elastic coal of low Young's modulus will be conducive to a wide fracture. Conversely, hard formations may be adjacent to the coal seam and have a constricted flow path in the fracture. The high modulus of adjacent rock contrasted with the low modulus of coal will contribute to confining a fracture in the coal, but the confinement from modulus is secondary to restraints to fracture growth from in-situ stresses.

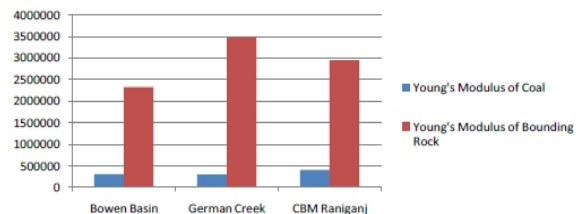


Figure 1: Young's Modulus Values

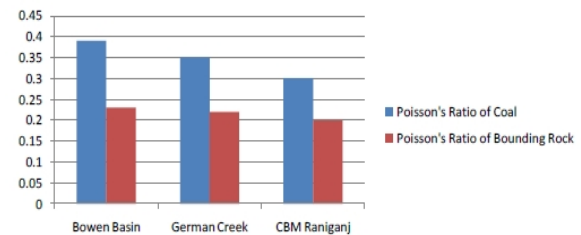


Figure 2: Poisson's Ratio Values

Poisson's ratio is an elastic property of rock that is a measure of the lateral expansion as compared to the longitudinal contraction for a longitudinally imposed

## Coal Bed Methane Geo-mechanics: Field Experiences & Developing a Computer Application

load or the ratio of transverse strain to longitudinal strain.

$$\mathfrak{Q} = \epsilon_y / \epsilon_x$$

$\mathfrak{Q}$  = Poisson's Ratio

$\epsilon_y$  = Lateral Expansion

$\epsilon_x$  = Longitudinal Deformation

A reservoir rock, deposited in a sedimentary basin, is subjected to a certain amount of pressure from the overlying rock layers. The vertical stress magnitude, at a specific depth, H, is given by

$$\text{Stress}_{\text{vertical}} = \sum \rho_n g h_n \quad \sum h_n = H$$

where  $\rho$  is the density of the overlying rock masses and  $g$  is the acceleration of gravity. The value of this stress component can be easily obtained from the integration of a density log. If such a log is unavailable, a rule of thumb of 1.0 to 1.1 psi/ft is generally a good approximation for this vertical stress component.

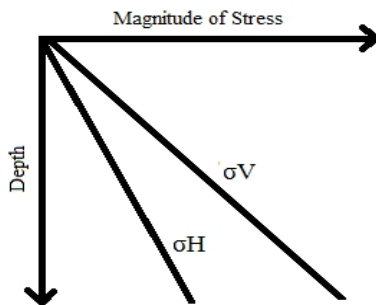


Figure 3: Original Stress Regime in Subsurface

For the case of elastic deformation with no outside influences (such as tectonics) in subterranean rock strata, there are two important things to note. First,  $\text{Stress}_{H_{\min}} = \text{Stress}_{H_{\max}}$ , as the stresses will be symmetrical on the horizontal plane. Secondly, as each individual unit of rock is pushing against another identical unit of rock with the same force, no deformation on the horizontal plane occurs.

$$\text{Stress}_{\text{horizontal}} = [\{\mathfrak{Q} (\text{Stress}_{\text{vertical}} - 2\alpha P)\} / (1 - \mathfrak{Q})] + \alpha P$$

Where  $\alpha$  = Biot's Constant

Hydraulic fractures are formed in the direction perpendicular to the least stress. Based on experience,

horizontal fractures will occur at depths less than approximately 2000 ft. because the Earth's overburden at these depths provides the least principal stress. If pressure is applied to the centre of a formation under these relatively shallow conditions, the fracture is most likely to occur in the horizontal plane, because it will be easier to part the rock in this direction than in any other. In general, therefore, these fractures are parallel to the bedding plane of the formation.

As depth increases beyond approximately 2000 ft., overburden stress increases by approximately 1 psi/ft., making the overburden stress the dominant stress. This means the horizontal confining stress is now the least principal stress. Since hydraulically induced fractures are formed in the direction perpendicular to the least stress, the resulting fracture at depths greater than approximately 2000 ft. will be oriented in the vertical direction.

In the case where a fracture might cross over a boundary where the principal stress direction changes, the fracture would attempt to reorient itself perpendicular to the direction of least stress. Therefore, if a fracture propagated from deeper to shallower formations it would reorient itself from a vertical to a horizontal pathway and spread sideways along the bedding planes of the rock strata.

The extent that a created fracture will propagate is controlled by the upper confining zone or formation, and the volume, rate, and pressure of the fluid that is pumped. The confining zone will limit the vertical growth of a fracture because it either possesses sufficient strength or elasticity to contain the pressure of the injected fluids or an insufficient volume of fluid has been pumped. However, while it should be noted that the length of a fracture can also be influenced by natural fractures or faults, natural attenuation of the fracture will occur over relatively short distances due to the limited volume of fluid being pumped and dispersion of the pumping pressure regardless of intersecting migratory pathways.

### Fracturing Anomalies & Conventional Problems

Most anomalies in fracturing coals result from uncommon values of properties of the coal reservoir,

## Coal Bed Methane Geo-mechanics: Field Experiences & Developing a Computer Application

such as rock mechanical properties and extensive natural fractures in the coals. As a consequence of these coal reservoir properties, induced fractures are very sensitive to complex in-situ stress profiles and the altering of those stresses when drilling and fracturing. Treating pressures may be higher than conventional reservoir fracturing. The cleat system influences the path of the fracture and may introduce multiple fractures to increase treating pressures. Rubble generated near the wellbore or fines introduced during fracturing may contribute to higher treating pressures.

Fines contribute to elevated pressures during fracturing. Fines are known to deteriorate fracture conductivity with time, possibly packing into secondary and tertiary natural fractures to damage permeability.

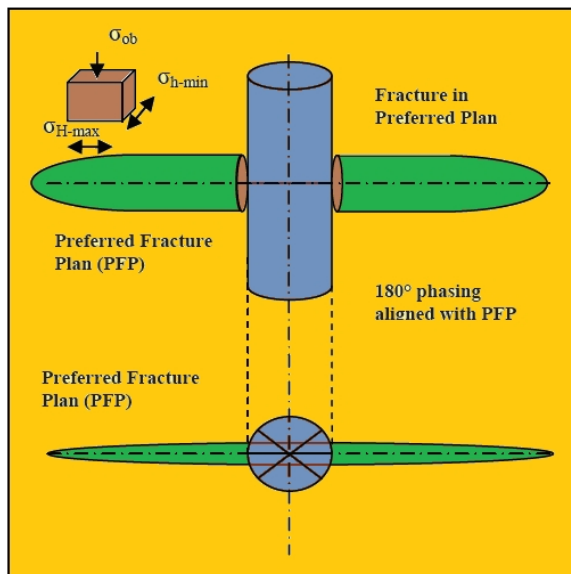


Figure 4: Preferred Fracture Plan as per Stress Values

Some research has helped explain qualitatively the contribution of fines to high fracturing pressures. Several mechanisms are offered. Fines could load the fracturing fluid to increase its viscosity and consequently increase pressure drop as the more viscous fluid moves through the fracture. Parting of the coal could create rubble and fines near the wellbore for a more tortuous flow path. The fines could pack in the tips of developing fissures or bridge elsewhere in the fracture to cause higher treating

pressures. A more important question revolves around the quantitative impact of fines on fracture treating pressures.

Laboratory burst-tests verify the generation of fines but in volumes that will not load the fracturing fluid appreciably. Therefore, there should not be excessive frictional pressure drops introduced by fines in the flow of the fluid through the fracture. More important effects on treating pressures come from fines concentrating near the wellbore to create high pressure drops in the fluids flowing through them. Injection falloff tests in CBM wells that reveal high skin factors are indicative of this.

Fines are also created from the attrition of the fracturing fluid, loaded with sand, flowing past the coal surface. A tortuous fluid path causing high-velocity fluid flow, such as near the wellbore or through opened butt or tertiary cleats, would contribute to the attrition of fines. Shear stresses on the coal that move one face of the fracture or cleat relative to the other face would also be expected to generate fines.

In many cases, it is desirable to perforate only the coal seams to avoid directing the hydraulic fracture treatment into a lower-stress sandstone or carbonate. The operator must then have a remedial process for alleviating damage caused by fines plugging the sand pack and wellbore area.

Another improvement in fines control is the use of a surface modification agent (SMA) on the surface of the proppant grains during hydraulic fracturing. It helps maintain a high well production rate for a longer period of time, enhances the frac fluid cleanup, reduces proppant settling to help improve permeability of the proppant pack and reduces proppant flowback.

A higher pressure than ordinary may be necessary to initiate a fracture in coal. With normal expectations of overburden pressure gradient of 1.0–1.2 psi/ft and of minimum horizontal stress of 0.6–0.8 psi/ft, the pressure to initiate the fracture should be approximately 100 psi greater than the minimum horizontal stress to create a vertical fracture, or no more than a 1 psi/ft gradient. Instead, a fracture gradient greater than 1.0 psi/ft is often encountered in coals.

## Coal Bed Methane Geo-mechanics: Field Experiences & Developing a Computer Application

The following mechanisms have been postulated to account for the higher than expected fracturing pressures in coal:

- Borehole instability or perforating causes rubble at the point of fracture initiation. Any stress relief of the coals results in breakup of the coal block. Drilling the wellbore, perforating, and even fracturing realign stresses surrounding the borehole. The unconsolidated coal chips retard initiation of the hydraulic fracture.
- Bursting of the rock at fracture initiation generates fines that bridge the crack near the wellbore. Further from the wellbore, the accumulation of fines and chips blocks the fracturing fluid front, redirecting the path of the fracture.
- Tortuous fracture path develops as the path follows a cleat, slippage at joints occurs, and horizontal components at the rock interface develop. A tortuous path may develop at the wellbore if the perforations are not aligned with the maximum horizontal stress. A network of fractures, multiple fractures, and parallel fractures develops.
- Fracture tip anomalies occur from fines at the tip or fluid lag. This is similar to but it occurs at the fracture tip.
- Raising pore pressures near the wellbore makes the coal subject to failure.

### Phasing Misalignment

Improper perforating can result in near-well screen outs if the perforations do not provide an adequate pathway to the main body of the fracture. In general, not all the perforations in a well are aligned with the preferred fracture plane. Indeed, it would be quite coincidental for this to be the case, even when special efforts are made to achieve it.

On the other hand, near perfect alignment will cause preferential propagation of one wing of the fracture with very limited penetration of the companion wing because of the restricted flow around the annulus. Nolte has pointed out that if the fracture does not initiate at the perforations, the fluid must communicate with the fracture through a narrow channel around the side of the casing. This channel can cause higher treating pressure due to width

restrictions. As with the tortuosity effect noted above, this can cause both increased pressure and screen outs due to proppant bridging. In addition, an elastic response (Poisson's effect) occurs in which the fracture opening results in a movement of the rock towards the wellbore.

Thus implementation of perforation for hydraulic fracturing needs to account for the perforation phasing with the preferred plane. It can be easily seen that for a 120° phasing two out of three perforations will closely approach the preferred fracture plane. This minimizes potential flow restrictions as realignment of the fracture with the preferred fracture plane takes place. For a well deviation of less than 30°, 120° or 60° misalignment, while a 0° preferred fracture plane (worst case scenario).

### Case Study

Hydraulic fracturing job in Well X1 located in Raniganj CBM block was carried out with a cumulative coal seam thickness of 3.07 m. The objective of hydraulic fracturing in these seams was to achieve a longer and wider fracture to enhance the water production from CBM well in order to produce CBM gas from coal seam.

The seam was perforated with an objective of lesser pressure drop due to perforation friction and tortuosity. The total 3.07 m of 1 zone was perforated via CTU.

<b>Well Name</b>	X1
<b>Casing</b>	7" OD, 6.33" ID
<b>Cement Tag</b>	1800 m
<b>Pay Zone Height</b>	3.07 m
<b>Formation</b>	Coal
<b>Perforation Size</b>	0.5"
<b>Perforation</b>	1537.5 m , 1536.5 m
<b>No of Cuts</b>	2

Table 1: Well Summary

	<b>Design(bbl)</b>	<b>Actual(bbl)</b>
<b>Prepad Stage</b>	192	272.2
<b>Slug Stage</b>	80	80.5
<b>Pad Stage</b>	190	190.2

## Coal Bed Methane Geo-mechanics: Field Experiences & Developing a Computer Application

<b>0.5 ppg Stage</b>	190	189.8
<b>0.5-2ppg Ramp</b>	40	40.2
<b>2 ppg Hold Stage</b>	190	142.6
<b>2-4 ppg Ramp</b>	30	0
<b>4 ppg Hold Stage</b>	150	0
<b>4-6ppg Ramp</b>	30	0
<b>6 ppg Hold</b>	20	0
<b>8 ppg hold Stage</b>	15	0
<b>Flush Stage</b>	187	0
<b>Misc.</b>	100	0

Table 2: Frac Job Design

Pumping Schedule and main Job plot shows that the job was carried out as performed up to 2 ppg ramp stage. Spikes in bottom hole treating pressure can be observed in the job plot at 2ppg stage. The job screened out even after varying the rate during 2ppg stage.

This can be an example for phasing misalignment creating a micro annulus through channel restriction at wellbore which often leads to early screenout (Romero et.al.). It is inferred from the above observation that the hydraulic fracturing job was screened out at a very early stage of 2ppg due to phasing misalignment of the perforation creating micro annulus which is blocked due to 16-30 sand leading to high friction and later it screened out.

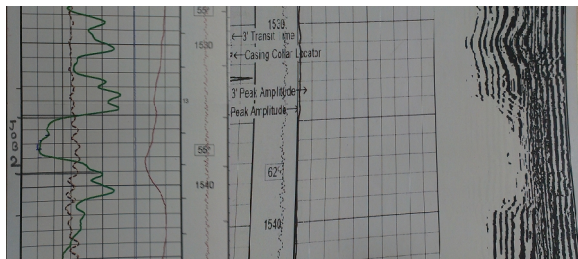


Figure 5: Caliper Log & Cement Bond Log across job zone

Another reason for the early screen out could be the larger caliper value at the perforation interval. The well is a bit washed out in the interval because of which the cement sheath between the well and casing is too thick which reduces the tunnel length going into the formation.

Thickness of Casing: 0.67"

Thickness of Cement Sheath: 2.5" (from caliper log)  
 Total thickness: 3.17"  
 Total CT Perf Tunnel Length (approx.): 4"  
 Tunnel Length inside the formation: 4" – 3.17" = 0.83"

### Accufrac: Computer Application

Accufrac is a Perforation & Hydraulic Fracturing based Software Application that can be installed on any windows computer and lets the user generate various results pertaining to these two processes.



Figure 6: Computer Application Home Screen

Accufrac has been designed by the authors keeping in mind the basics of Perforation & Fracturing and is targeted at beginners for their easy understanding of the process as a whole and the mathematical relations related to them. It covers Rock Mechanics, Pressures, Perforation Physics, Fluid & Proppant Selection, Fracturing and Frac Chemicals. It is an open source application so that anyone can download and install it.

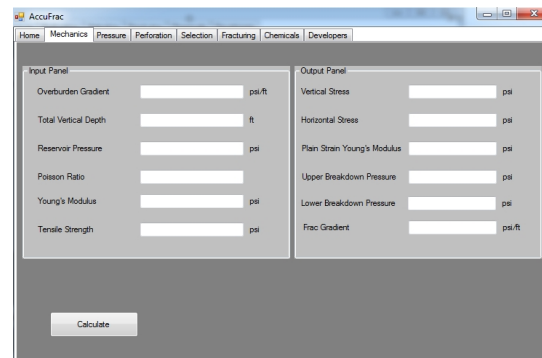


Figure 7: Computer Application Rock Mechanics Tab

## Coal Bed Methane Geo-mechanics: Field Experiences & Developing a Computer Application

For rock mechanics, the user has to provide basic inputs like Overburden Gradient, Total Vertical Depth, Reservoir Pressure, Poisson Ratio, Young's Modulus, Tensile Strength of formation. The application provides the user with calculated values of Vertical Stress, Horizontal Stress, Plain Strain Young's Modulus, Upper & Lower Breakdown Pressure & Frac Gradient of the formation.

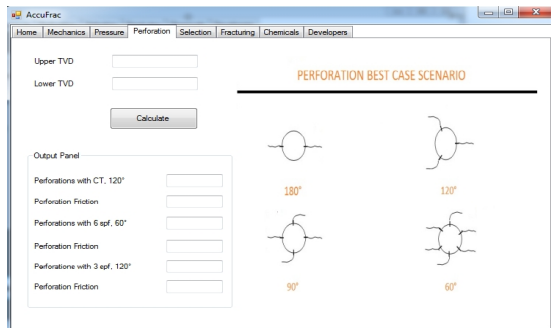


Figure 8: Computer Application Perforation Tab

For pressure calculations, the inputs taken from the user are TVD, Specific Gravity, Perforation Diameter, Number of Perforations, Slurry Rate, STP, Frac Gradient, Tubing Diameter and Viscosity. The output includes Hydrostatic Pressure, Tubular Friction, Perforation Friction, BHTP, and Friction Factor.

Similarly Perforation, Frac Fluid & Proppant Selection, Fracturing calculations and chemicals used can be evaluated using this application.

### Conclusion & Recommendations

- Geo-mechanics plays an integral role in exploitation of CBM reserves and affects production significantly if not taken properly into account.
- There have been observed many cases of poor injectivity in some coal seams due to neglect of Geo-mechanics. Remedial operations like prolonged acid soaking or extra perforation are done in such cases.
- Since Hydraulic fracturing is being carried out on large scale in the Raniganj field, stress oriented perforation may provide better results and lesser early screen outs.

- If provided with accurate stress data in horizontal and vertical directions it is possible to align the perforations for optimized zonal fracturing which will provide low bottomhole treating pressure. The authors recommend a seismic survey for better results.
- The computer application developed helps in understanding the calculations involved with ease and simplifies the process of decision making.

### References

- Kothari, N., Mahajan, M., Pooniwala, S., and Panjwani, J., 2013, Application of Sand Jet Perforation for Multizone Fracturing in CBM Wells, India; Baker Hughes.
- Ceccarelli, R. L., Pace, G., Casero, A., Ciuca, A. and Tambini M., 2010, Perforating for Fracturing: Theory vs. Field Experiences, ENI.
- Sharma, A. and Pathak, H., 2013, Stimulation Optimization of Coal bed Methane Wells using Coiled Tubing, Halliburton.
- Adil, F., Sharma, A. and Bhat, S., 2012, Hydraulic Fracturing of CBM Wells in India Using a Unique Fracturing Service Technology – Operational & Technological Lessons, Halliburton.
- Economides, M. and Nolte, K., 1989, Reservoir Stimulation.
- Cosad, C., 1992, Choosing a perforation strategy, Schlumberger Oil Field Review.