Hydraulic fracturing lab experiments in tight formations

V. Rasouli*

Department of Petroleum Engineering
Curtin University, 6151 Perth, Australia

*Corresponding Author's E-mail: v.rasouli@curtin.edu.au
Keywords: Hydraulic fracturing; unconventional reservoirs; True triaxial stresses; upscaling; interaction mechanism.

Abstract

Hydraulic fracturing is perhaps the major stimulation technique which is used to enhance production in low permeability reservoirs and also in unconventional resources such as tight formations, shale gas and Coalbed Methane. Performing lab simulations, before real field practices, to understand different aspects of complicated process involved in a fracturing job would be very beneficial. For this purpose, and in order to consider the effect of all three principal stresses in the field the experiments must be conducted on a cube shaped sample. Using the true tri-axial stress cell (TTSC) developed at the Department of Petroleum Engineering of Curtin University it is possible to simulate a fracturing job on samples up to 30cm. Three independent stresses can be applied to the sample with pore pressure being increased independently. The fluid injection causes the fracture to develop within the sample.

We have performed lab experiments on very small size cube samples of 5 cm. No similar experiments have been reported in the literature which is believed to be due to the need for expensive laboratory set up and accurate measurement facilities. This is while the maximum sample size that can be retrieved from downhole is no more than 5 cm: this indicates the importance of lab experiments on this sample size. The initial experiments carried out on synthetically made samples and on a few real tight sandstones indicated very successful results which supports the idea of testing small scale samples.

Performing hydraulic fracturing in the lab on small size samples with the objective of upsclaing the results to represent real field practices needs applying the scaling laws. Different scaling laws proposed in the past have been used in this study to investigate their applications on tight formations. It was possible to conduct this study on synthetically made samples with different sizes and assess the applicability of the scaling laws. The preliminary results are in a relatively good agreement with numerical simulations which were performed for calibration purposes.

The results of some of the lab experiments performed using the TTSC will be presented in this paper and conclusions will be made.

1. Introduction

Unconventional reservoirs are different from conventional resources in that they need some kind of stimulation techniques to increase their permeability. Tight gas, shale gas and Coal seam gas (CSG) are typical unconventional resources which have brought great attentions in the past few years for gas production [House & Shemeta, 2008; Medeiros, *et al.*, 2008]. Hydraulic fracturing is a technique which is used to provide a larger exposure of the hydrocarbon to a fracture surface through which the it travels towards the wellbore.

The optimal design of the hydraulic fractures is impeded by insufficient information on the rock mass structure and the in-situ stresses and insufficient understanding of their effect on the fracture propagation. In addition, numerical modelling of hydraulic fracturing is difficult, as it involves the coupling of at least three processes: the mechanical deformation induced by the fluid pressure on the fracture surfaces, the flow of the fluid within the fracture, and the fracture propagation [Adachi, *et al.*, 2007). As a result, the hydraulic fracturing simulators do not predict the correct wellbore fluid pressure or fracture geometry even in simple cases (e.g., Carter, *et al.*, 2000).

Another method of designing the hydraulic fractures is to conduct experiments of hydraulic fracturing of laboratory rock models with subsequent upscaling of the obtained results using the appropriate scaling laws (e.g., de Pater *et al.*, 1994; Bunger *et al.*, 2005; de Pater & Beugelsdijk, 2005; Adachi, *et al.*, 2007).

The presence of a large scale structure in the rock mass complicates the upscaling. For instance, the most common feature - the presence of pre-existing natural fractures can considerably affect the hydraulic fracture propagation (e.g. Caballero & Dyskin, 2008). Experiments on the influence of pre-existing fractures on the hydraulic fracture propagation have mainly been conducted on homogeneous, non-permeable materials. Thus, they have been unable to reproduce the effect of the leak-off which is one of the controlling parameters of the process. Another shortcoming of the existing experiments is the restricting range of principal stresses as making all principal stresses different would require the use of a rarely available true triaxial loading frame.

The true triaxial stress cell (TTSC) developed at Curtin Petroleum Engineering Department (Rasouli & Evans, 2010) offers the ability to apply pore pressure to the sample using the sealing system and is equipped with seismic transducers for monitoring fracture propagation. Also, the system has the capacity to independently apply three high stresses to the sample, the possibility of applying pore pressure and the ability to attach acoustic transducers using the specially made space for monitoring the hydraulic fracturing propagation. In particular, a cubic sample of 10 cm could be loaded to about 25 MPa at each axis with the independently applied fracturing fluid pressure up to 21 MPa. This unique system will permit scalable testing and monitoring of microfracturing under realistic stress conditions.

In this paper, after a brief review of the TTSC features, the results of experiments carried out on a synthetically made sample and one real tight sandstone rock will be presented. It is discussed how the results of these experiments could be used for improved field operation.

2. Hydraulic fracturing experiments

Figure 1 shows a general view of the TTSC which was used for hydraulic fracturing experiments in this study. The horizontal stresses are applied independently through two rams shown in this figure. The horizontal stresses are transferred into the plates shown in the top picture in Figure 1 and then to the sample. In the bottom picture on the right special shims are shown which are used to accommodate a 20 cm block for testing.

Figure 1: True triaxial stress Cell (TTSC) in left with top views in right. The bottom picture shows special shims used to accommodate a 20 cm cube sample.

For scaling analysis synthetic samples with different sizes are required to be built. A range of sample sizes that we use in the lab is shown in Figure 2 (left). Figure 2 (right) shows a 20 cm cubic frame (mould) which is used for this purpose. Sample preparation requires a great care as the results could be affected by sample inhomogeniety or existence of bubbles inside the sample.

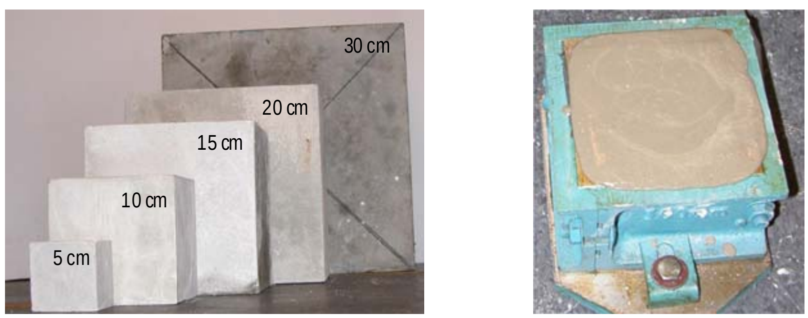

Figure 2: Range of synthetic samples with different sizes built for fracturing tests (left) and a 20 cm mould used for making synthetic samples.

To conduct a hydraulic fracturing experiment a hole is drilled in the middle of the sample. The injecting fluid is applied to an approximately one third of the middle height of the sample. For this purpose, one side of the hole is covered by the injecting tube which is inserted into the hole whereas the other side is engaged with a metal bar. This approach appeared to produce more realistic fracture geometry than when the hole is not drilled through the entire sample height. The fluid is then injected at a constant flow rate and the pressure versus time data are recorded using a data recorder which is connected directly to a PC and a monitor.

3. Test results

Figure 3 shows an example output plot of pressure-time obtained for a 20 cm mortar sample with two vertical fractures. The objective in this experiment was to investigate the interaction mechanism when the hydraulic fracture intersects the plane of natural fracture [Rasouli, 2011]. The artificially made fracture planes were filled with strong cement to simulate a competent interface. It is to be noted that for this test the scaling analyses were not performed as the objective was not to correlate it to any field application.

The fracture planes after the experiments are shown in Figure 4. In this figure (right side picture) the invasion zone of honey, which was used as injecting fluid is visible. The induced fracture propagated vertically and the propagation was along a direction close to the maximum horizontal stress. Also, the induced fracture, as is expected for a strong interface, could cross the interface.

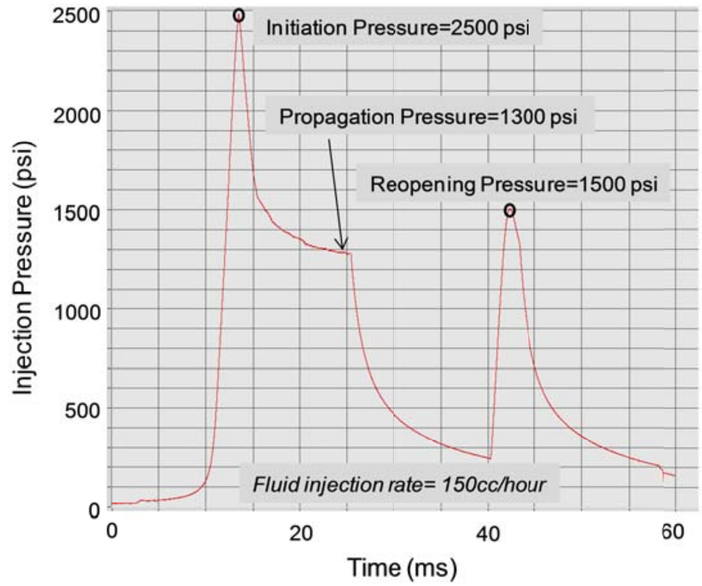

Figure 3: Pressure-time plot for hydraulic fracture experiment of a 20 cm mortar block [Rasouli, 2011].

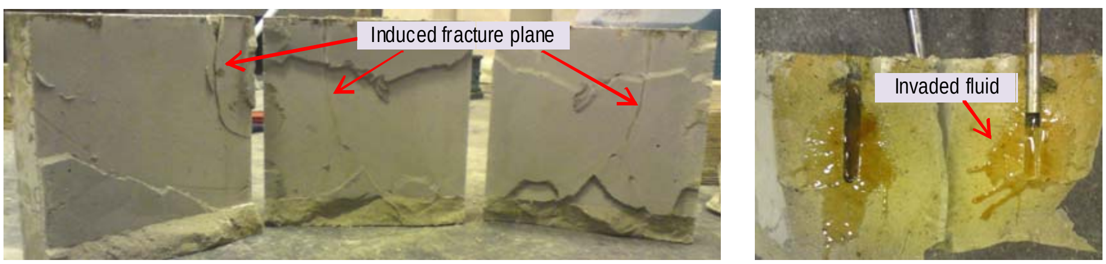

Figure 4: Induced fracture planes after HF test (left) and the injecting fluid invasion zone.

In another experiment carried out on 5 cm tight sandstone shown in Figure 5 (left), an initiation pressure of 4400 psi was recorded. This was a competent rock with Young's modulus of 45 GPa and a UCS of approximately 180 MPa. The invasion zone of honey after the experiment is shown in Figure 5 (right). The fracture propagated along the maximum stress direction and as the scaling analysis was not performed the fracture reached the boundaries of the sample. Again, here the objective was to ensure that the fracture can develop under the existing loads and fluid properties. Further experiments with scaling analysis are currently undergoing.

Figure 5: A 5 cm tight sandstone cube before (left) and after (right) hydraulic fracturing experiment.

The results of these experiments when carried out considering scaling analysis and on samples with different sizes would be useful to better predict the hydraulic fracturing behaviour in field operation. As depicted in Figure 6 the TTSC allows experiments to be conducted on specimens with sizes larger than conventional samples used in rock mechanics labs. The maximum size of 30 cm is close to log resolution and in this way the results of lab experiments could be compared with log data and hence field operational results.

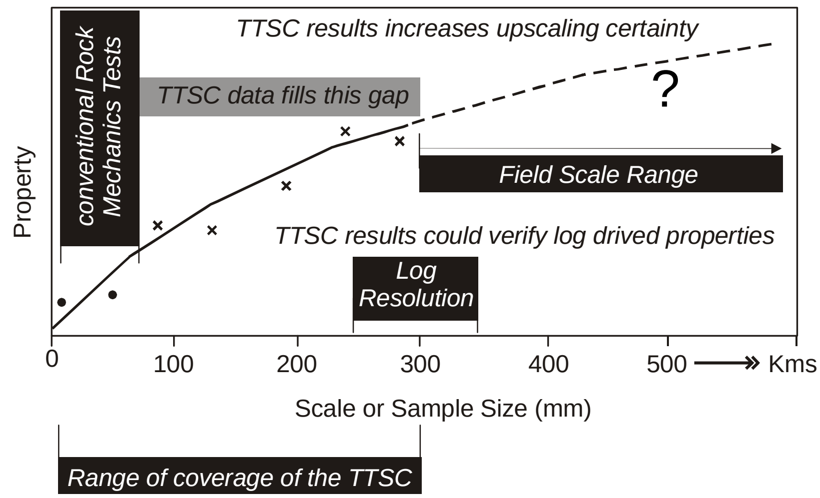

Figure 6: Larger range of sample sizes could be tested using the TTSC than conventional rock mechanics equipments (Rasouli & Evans, 2010).

4. Conclusions

The true triaxial stress cell (TTSC) is advantageous for hydraulic fracturing experiments in the sense that three independent stresses can be applied to the rock sample. It was shown how using a synthetically made mortar sample the interaction mechanism when a hydraulic fracture approaches a natural fracture plane can be studied. In this case, for a strong interface the hydraulic fracture crossed the interface. The TTSC allows testing samples with any size below 30 cm and thus the results corresponding to different scales could be correlated with each other to check the capability of the existing scaling dimensionless numbers. It was concluded that the correct test is one which is carried out based on scaling analysis.

Acknowledgement: The Author would like to thank Mr Mohammad Sarmadivaleh, a current PhD student at the Department of Petroleum Engineering of Curtin University, for conducting the lab experiments.

References

1. Adachi, J., Siebrits, E., Peirce, A. and Desroches, J. Computer simulation of hydraulic fractures. *Int. J. Rock Mech., Min. Sci.* **44**, 739-757, 2007.
2. Bunger, A.P., Jeffrey, R.G. and Detournay, E. Application of Scaling Laws to Laboratory-Scale Hydraulic Fractures. *American Rock Mechanics Association (ARMA)*. 2005.
3. Caballero, A. and Dyskin, A.V. Mesh scalability in direct finite element simulation of brittle fracture. *Engineering Fracture Mech.* **75**, 4066-4084, 2008.
4. Carter, B.J., Desroches, J., Ingraffea, A.R. and Wawrzynek, P.A. Simulating fully 3D hydraulic fracturing. In: Zaman M, Booker J, Gioda G, editors. *Modeling in geomechanics*. New York: Wiley Publishers. 2000.
5. de Pater, C.J., Cleary, M., Quinn, T., Barr, D., Johnson, D. and Weijers, L. Experimental verification of dimensional analysis for hydraulic fracturing. *SPE Prod. Facil.* **9**, 230-238, 1994.

6. de Pater, C.J. and Beugelsdijk, L.J.L. Experiments and numerical simulation of hydraulic fracturing in naturally fractured rock. *The 40th U.S. Symposium on Rock Mechanics (USRMS)*, 2005.
7. House, N. and Shemeta, J. Understanding Hydraulic Fractures in Tight-gas Sands through the Integration of Borehole Microseismic Data, Three-dimensional Surface Seismic Data, and Three-dimensional Vertical Seismic Profile Data: A Jonah Field Case Study. *AAPG*. 77 – 86, 2008.
8. Medeiros, F., Ozkan, E. and Kazemi, H. Productivity and Drainage Area of Fractured Horizontal Wells in Tight Gas Reservoirs. SPE Reservoir Evaluation & Engineering. **11**, 902-911, 2008.
9. Rasouli, V. A true triaxial stress cell (TTSC) used for simulations of real field operations in the lab. *The 12th ISRM International Congress on Rock Mechanics. Beijing*, October 18-21. 2011.
10. Rasouli, V. and J.B. Evans. A True Triaxial Stress Cell (TTSC) to simulate deep downhole drilling conditions. *APPEA Journal*. **50**, 61-70, 2010.