Chapter 44

Hydraulic Fracturing Mine Back Trials — Design Rationale and Project Status

Peter K. Kaiser, Benoît Valley,
Maurice B. Dusseault and Damien Duff

Additional information is available at the end of the chapter

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Abstract

Last year, a joint Mining and Oil & Gas industry consortium was established in Canada to conduct hydraulic fracturing (HF) tests accompanied by a mine-back of fractured regions to assess HF models and microseismic monitoring data during controlled experiments. Details about the displacement field, fracture aperture and extent, and micro-seismic parameters could then be verified and used as calibration data for modeling of HF processes in igneous and dense sedimentary rocks.

Various injection experiments are planned and they will include pre-fracturing rock mass characterisation using best available current techniques, dense arrays of multi-parameter wall and borehole-mounted instruments, and the treated volume will be mined through to assess fracturing effectiveness, existing fractures and new fracture interactions, and to determine if pathways can be identified for improving currently available numerical and fracture network modeling tools.

In this paper we present the results of the experimental design and planning phase, outlining objectives and justifications for planned experimental layouts. Preliminary plans for a first mine-through trial at Newcrest Mining's Cadia East mine in New South Wales, Australia are described. The hypotheses advanced in this experimental design, supported by evidence from the literature, are that activation and development of a fracture network by hydraulic stimulation is possible if the injection procedure is designed such that injection pressures and rates are maintained within an optimal window, thereby producing conditions under which effective stress management for risk mitigation in deep mining can best

be achieved. The evaluation of these hypotheses is the focus of the current high level experimental plan presented in the paper.

Keywords stress management, stiffness modification, shale gas analogue, mine-back experiments, model calibration, hydraulic fracture, naturally fractured rocks

1. Introduction

Hydraulic fracturing (HF) has been widely used in the oil & gas (O&G) and mining industry: in O&G to stimulate reservoirs [1] and in mining, primarily to initiate caving and to improve fragmentation (e.g. [2-4]). Attempts have also been made to initiate slip on faults or shears [5] and research including mine-backs of hydraulically fractured zones has been conducted [6,7] in order to better understand the characteristics of the propagated hydraulic fractures. However, to the authors' knowledge, although there are many anecdotal indications of hydraulically induced changes to rock mass properties and stress, hydraulic fracturing has so far not been successful in inducing sufficient changes in the in situ or mining-induced stress field to be of practical value for risk mitigation related to violent seismic energy release in deep and high stress mining. It is speculated that the latter can only be achieved by the stimulation, mobilisation and enhancement of a natural fracture network rather than by solely generating a new system of induced hydraulic fractures. Hence, an innovative testing program, focussed on natural fracture network stimulation and the development of these techniques for stress management purposes is pursued. The mobilisation and development of a fracture network is also relevant for the optimal exploitation of tight gas or oil shale reservoirs, which closely resemble hard-rock situations (low permeability block, naturally fractured, stiff, low to moderate Poisson's ratio, etc.). The success of the proposed hydraulic injection program will be investigated during a mine-back test, and the results applied to mining and O&G applications.

In this paper, the results of the experimental design phase, outlining objectives and justifications for planned experimental layouts, are presented. Preliminary plans for the first mine-through trial at Newcrest Mining's Cadia East mine in New South Wales, Australia are described.

2. Project objectives

The practical justification for the overall HF project is different for the mining and O&G sector consortium sponsors. However, both sectors are interested in advancing the state of knowledge in three broad areas: (a) fracture network stimulation and development, (b) stress field modification, and (c) micro-seismic data interpretation during hydraulic fracturing and reservoir stimulation. Hence, the broad objectives of the program meets the primary needs of both sectors and will advance the understanding of hydraulic fracture network stimulation

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based on experiments permitting near-field monitoring followed by investigation of the treated volume via mapping and monitoring during mine-through.

2.1. Mining perspective

Various hydraulic fracturing (HF) experiments have been undertaken in mines, some with mine-through experiments (e.g. [6]) for various purposes: to better understand fracture propagation, fracture interaction with natural joints, fragmentation changes, penetration of proppants, etc. Successes have been reported with respect to the use of HF for rock mass preconditioning, for rock fragmentation and cave initiation (e.g. [2]) but unanswered questions remain about its effectiveness in affecting stress redistribution and in controlling energy release from critically stressed rock mass structures. There are much anecdotal but little scientifically proven evidence that HF can help manage stresses, or not. The authors suggest that it may be the methodology of fracturing that may be the source of the apparent contradictions reported in the literature. As mines progress to greater depth stress management for the control of seismically releasable energy becomes of strategic importance. Furthermore, with the introduction of mechanized excavation techniques for rapid mine development (e.g., by Rio Tinto, AngloGold Ashanti, and others), new risks related to strain-bursting are introduced because of the less-damaging nature of these excavation techniques.

For the mining sector the motivations are to broaden the application of hydraulic fracturing and rock mass stimulation beyond cave initiation, propagation and fragmentation management by introducing methodologies for hydraulic stress and rock mass stiffness management that will eventually find introduction for risk mitigation in deep and high stress mining operations. In particular, the problem of fault-slip rockbursting is perplexing and, it is thought, can possibly be addressed through the creation of "damage zones" around potentially unstable structures, thereby reducing the energy emission levels and rates and improving constructability in highly stressed ground.

It is hypothesised that current hydraulic injection techniques deployed in cave mine applications are predominantly propagating hydraulic fractures and that shear dilation is a secondary process. Indeed, opening Mode I fractures develop within a narrow (almost planar) zone normal to σ_3, and their irregular nature promotes asperity locking resulting in little final net shear strength or stiffness reduction. It is recognised that as fluids are lost in the rock mass surrounding the hydraulic fracture some distributed shearing of critically oriented natural fractures will also occur (e.g. [3]), however in order to enable stress management, one must promote volumetrically distributed irreversible changes to the rock mass and the development of injection techniques that achieve this objective is at the core of the planned research. Section 3 presents the output of a review of current injection practices for various applications and their effect on the rock mass. It served as background for the development of the experimental approach presented in Section 4.

2.2. O&G perspective

The advent of numerous staged HF stimulations along the lengths of deep horizontal wells [8] has unlocked huge quantities of natural gas and oil in low permeability formations that had heretofore been considered non-commercial. Typically, a 1 to 2 km long horizontal well (Fig. 1) is drilled parallel to σ_3, and a series of hydraulic fractures are installed along the length of the well, injecting into one or several perforated or open sites each time, until from 10 to 40 sites are fracture-stimulated. The optimum design of each stage is still the subject of considerable debate, in part because existing mathematical models of fracturing, founded on single-plane Sneddon crack type assumptions in unjointed continua, are inadequate to predict fracture length, stimulated volume, or surface contact area in naturally fractured rock and more complex approaches using fracture network models are difficult to calibrate. Thus, design is largely empirical, based on remote field measurements that may be inadequate or difficult to interpret (tilt measurements, microseismic measurements and post-fracture well tests). For each new field, there is an extensive period of experimentation with different sequences of fluids and proppants, using different rates and materials, along with limited field measurements (generally microseismic monitoring) to try and optimize the stimulation process to achieve a maximum contacted volume without wasteful fracture propagation into non-productive overlying strata. Each stimulated well may cost 5-10 million dollars, and the eastern United States Marcellus Shale alone may require over 500,000 wells for complete development, as the deposit covers over 95,000 square miles, and at least 6 horizontal wells are needed for each square mile (100 acre spacing). Furthermore, the deeper lying Utica Shale, which also extends into Canada, will eventually be developed, requiring a similar number of wells [9, 10]. Sub-optimal fracture design because of incomplete understanding and inadequate predictive tools quickly becomes a costly luxury.

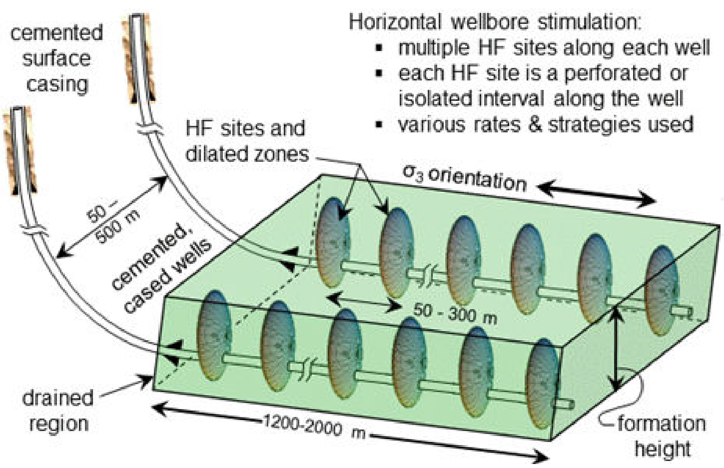

Figure 1. Staged hydraulic fracturing along a horizontal well axis for shale gas stimulation.

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