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Experiment simulation of hydraulic fracture in colliery hard roof control

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ABSTRACT

Hydraulic fracture geometry is of paramount importance to enhance fracture effect in colliery hard roof control. Near wellbore complexity often resulted in low lateral dimension of induced fracture hence the fracking effect of the treatment. In the past, near wellbore fracture geometry is mainly believed to be controlled by the interaction between hydraulic fracture initiation and natural fracture infiltration/opening. Recently, lab experiments have proved that transverse notch plays a role in lowering breakdown pressure and also in reducing near wellbore complexity. Besides, colliery hard roofs are often overpressured, therefore, with the increase of pore pressure, the influence caused by stress difference is weakened, and the role of notch becomes significant. In this paper, a series of lab experiments are conducted to gain in-depth understanding of the role transverse notch plays on near wellbore geometry and fracture reorientation. Hydraulic fracture process is physically simulated by injecting water (green dyed) at some certain rate into a pre-installed tube in a block ($300 \times 300 \times 300$ mm) under tectonic stress condition. Different notch parameters and fracturing regimes are used to make comparison. The notch changes the local stress and strain field in the blocks and affects the way blocks deform and fail. Post-mortem analysis and photo image of the block clearly show: (i) the length and angle of initial notch play a role in determining: near wellbore geometry and fracture reorientation; (ii) near wellbore fracture complexity may be reduced by making a longer initial notch and picking an appropriate notch angle; (iii) better understanding can be achieved by conducting further researches under normal stress condition and taking more factors into consideration.

1. Introduction

Hydraulic fracturing, since its first successful application to petroleum industry in 1940s (Gidley et al., 1989), has been intensely investigated for tens of years. As a maturing technology, hydraulic fracturing is originally developed to increase gas and petroleum production. For example, a most widely used method to stimulate reservoir is injecting viscous fluid with sorted sand (proppant) into oil and/or gas layer (Adachi et al., 2007). Rocks including shale, sandstone and coal are fractured in order to create more surface area and retrieve the gas or oil in it. Thus, hydraulic fracturing can significantly increase the effective permeability of the rock formation and is very effective in improving the recovery of hydrocarbons.

In mining industry, hydraulic fracturing is also a crucial approach to resolve modern technical challenges such as hydrocarbon recovery from low-permeability coal seam, hard roof fracturing in fully mechanized top coal caving and rock burst control (Jeffrey and Mills, 2000). Generally, drilling and blasting method is still a priority way to deal with hard stable roof, however, with some main disadvantages (Feng and Kang, 2012) which are: (a) high cost caused by using large amount of explosives and dealing with underground air pollution; (b) extra preparations are needed to prevent gas or coal dust explosion when used in gassy mine or coal seam; (c) for the shallow buried coal, blasting may cause threat to the ground buildings. For example, when using advanced deep hole pre-splitting blasting method in Wangtaipu (Zonglan, 1997) Colliery in Shanxi province, blasting vibration can be clearly felt by people on the ground village, causing very negative social reflection there. In some coal mine where high volume flammable gas exists, ordinary drilling and blasting method cannot be applied, thereby making hydraulic fracturing a most commonly used alternative to crack the hard and stable roof, relieve the high roof pressure and protect personnel and facility. A typical fracking process includes, (1) drill one or several holes into

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the target roof rock; (2) make initial notch using special cutting drill; (3) seal the bottom hole section with a hole packer or cement mortar and inject water. The effect of injecting water is mainly twofold (Wang et al., 2015). Firstly, injected water can to some extent reduce the strength of rock; secondly, several main hydraulic cracks and airfoil branch fissures can be formed to relieve the high roof pressure. An effective treatment requires generating enough fractures which could fully cut the hard roof rocks, in order to avoid casualty and facility damage resulted from large rock fragments falling. On the other hand, hydraulic fractures are also supposed to be controlled to propagate in a certain range, preventing from penetrating other layers such as brine and aquifer. Therefore, it's of paramount importance to choose correct fracturing parameters, such as fluid injection rate and fluid viscosity, as well as developing appropriate protocols for controlling the propagation of the hydraulic fracture fronts. So far many factors such as in-situ stress, injecting rate, pre-existing discontinuity and fluid type have been intensively investigated to gain more understanding on the fracturing process (Warpinski and Teufel, 1987; Blanton, 1982; Zhou et al., 2008; Bohloli and de Pater, 2006) thousands of miles beneath ground. However, many field data (Wang et al., 2008; Jeffrey and Bunger, 2009; Fisher and Warpinski, 2012) suggests that in some cases hydraulic fracture may still penetrate into a water bearing layer or grow into an unwanted zone. Catastrophic results may also occur when a high-pressure bottom aquifer exists, which may even result in damage to the mine pressure system (Puri et al., 1991).

In principle, the fracture can initiate anywhere along the open borehole section, depending mainly on permeability variation and existing flaws. However, if a manmade radial notch can be cut in a way that it dominates local natural variations, the number of hydraulic fractures could be controlled and the expected fracture geometry may be achieved (Lhomme et al., 2002). In this study, factors including angle/length of the initial notch and injecting rate are investigated, direct comparison is made after fracturing. In the end, some clear conclusions are drawn.

2. Experiment preparation

2.1. Experiment setup

The experiment setup is a servo controlled tri-axial testing system, which consists of a steel framework, a loading system and a servo injecting pump (Fig. 1). The testing blocks are placed in a loading cell connected to 3 pairs of flat jacks, the pressure of which could be controlled separately by a multi-channel hydraulic voltage stabilizer. The tri-axial stress state is mimicked through a piston positioned between a cubic specimen and the reaction frame. The maximum stress could reach up to 28 MPa. Generally, the working medium of the hydraulic pump is power oil. So when using water or other medium as fracturing fluid, an oil–water isolator device is set in the pipeline to separate them. The hydraulic pump used here could generate a maximum of 140 MPa injection pressure, controlled by a MTS 816 servo system, which could also continuously monitor the block deformation during fracturing.

When running the test, data such as injection pressure/rate, sample displacement and tri-axial stress state are automatically recorded by computer.

2.2. Blocks preparation

Before test, roof rock samples were obtained from field site at Tashan coal mine of Datong Coal Mine Group, Shanxi Province. These core-throughs were processed to 6 standard core samples for uniaxial compression test, in order to measure mechanical properties of the roof rock. The blocks were made of analog material to ensure reproducibility and simplicity. The analog material used here was a mixture of Chinese cement No. 325 and fine sand which was sieved by a screen shaker. A series of parameter tests with different ratio of mixture and water were performed to ensure that the strength, Young's modulus and Poisson ration of specimen were close enough to that of the real roof rock. Generally, the mass ratio (cement: sand) is designed to control the strength of the blocks while the volume ratio (water: mixture) is picked to reach the best workability. In the end, as shown in Table 1, a mass ration (cement: sand=1:1) and a volume ration (water: mixture=0.4:1) were found to optimize the result.

The cubic blocks were cured in a mold with an inner dimension 300 × 300 × 300 mm for 3 days, and then transferred to room temperature environment for another 2 days (Zhou et al., 2010). During curing process, a special designed steel tube was installed to the depth of 150 mm across the complete block perpendicular to the surface. Initial notch was simulated by 2 circular steel plates with 3 mm spacing. The parameters of initial notch were varied systematically, as shown in Table 2. The geometry of the test block and the special tube are shown in Fig. 2.

The cubic samples were polished to avoid any pressure inhomogeneity. Teflon sheets and Vaseline were also used to minimize shear stress developed between the pressure platens and the block.

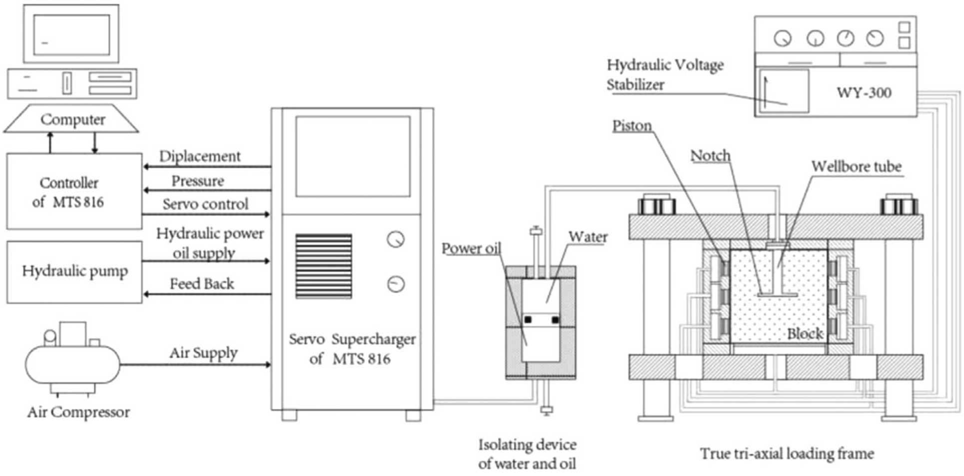

Fig. 1. Schematic of the experiment setup (Zhou et al., 2008).