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FRACTURE INITIATION USING TAILORED-PULSE LOADING

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FRACTURE INITIATION USING TAILORED-PULSE LOADING*

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ABSTRACT

Conditions to produce multiple fracturing of boreholes are examined for sandstone samples having a dry density of 2.42 Mg/m^3 and 8.9 percent porosity. Tailored-pulse loading experiments are performed with borehole pressures ranging from 10 to 100 MPa, loading rates from 10^{-4} to 10^2 MPa/ms and pulse durations from 10 to 50 ms. Samples are tested for initial states of dry, quasi-dry, and total saturation with confinement pressure varying from 0.1 to 50 MPa. Data show sensitivity of multiple fracture initiation on loading rate, water content, and confinement pressure.

INTRODUCTION

Over the past few decades, techniques to enhance the recovery of resources from reservoirs have mostly been hydrofracturing and explosive shooting of wells.

For hydrofracturing, a section of a well is pressurized at rates normally lower than 1 MPa/s producing two fractures on opposing sides of the wellbore that tend to propagate in a direction perpendicular to the least principal stress¹. The induced fractures can usually be extended to large distances².

Detonating an explosive in a wellbore generally creates a large number of fractures of short extent. The rate of pressurization is equal or greater than 10^7 MPa/s . The high explosive stress environment can cause compaction or pulverization of a finite zone around the wellbore to such a degree that permeability is significantly decreased as demonstrated by Kusubov et al.³

If we consider the limitations of hydrofracture and explosive shooting, it is apparent that a technique for initiating and sustaining multiple fractures in a wellbore should generate a pulse with a rise time fast enough to initiate multiple fractures and of a duration long enough to sustain multiple fractures. As demonstrated by Warpinski et al.⁴, tailored-pulse loading at intermediate rates of loading can create multiple fractures without damaging the wellbore region.

TAILORED-PULSE LOADING TECHNIQUE

The generation of tailored-pulse loading to boreholes of samples that may be confined under a specified confining pressure

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is achieved with the pressure vessel and flywheel-rotating shaft apparatus described by Swift and Kusubov⁵. The borehole of a cylindrical rock sample confined in a pressure vessel is filled with water, oil, or some other fluid. The reservoir fluid is displaced by a piston to provide prescribed loading conditions of the borehole. Borehole pressure is monitored by a piezoelectric pressure transducer located at the bottom of the borehole, and its output is recorded on an oscilloscope and a high-speed digital recorder. A few of the tailored-pulse loading conditions that can be obtained with the flywheel-rotating shaft apparatus are shown in Figure 1.

Figure 1. Typical "sawtooth" tailored-pulses using water.

TAILORED-PULSE LOADING OF NUGGET SANDSTONE

Over 50 experiments were performed on samples of Nugget sandstone to determine its susceptibility to multiple fracturing at intermediate loading rates and to define threshold conditions for multiple fracture initiation. The effects of different *in situ* conditions that could be encountered in borehole wells in the *field* were examined by varying the initial environmental conditions of the samples to include dry, quasi-dry and fully saturated states along with pressure confinement of 0.1, 15, and 25 MPa. Quasi-dry samples, although originally dry prior to fluid being introduced into the borehole during the test setup, have a thin region around the borehole that is partially-to-fully saturated by the intrusion of fluid from the borehole. For the dry case, the initial fluid intrusion was prevented by either a thin coating of epoxy around the borehole or a 0.05-mm-thick copper liner.

PREPARATION AND POSTSHOT TREATMENT OF SAMPLES

Cylindrical samples, 13 cm in diameter by 15.3 cm long, were cored perpendicular to the bedding planes from blocks of Nugget sandstone quarried near Salt Lake City, Utah. Each sample had a borehole of 1.43 cm in diameter drilled along its axis. The

samples were coated on the top and sides with an 0.7-cm-thick layer of epoxy to maintain the water content of fully saturated samples and to prevent intrusion of the confining fluid into the sample during confined experiments. The average dry density of the samples was $2.42 \pm 0.01 \text{ g/cm}^3$ with a gas porosity of 8.9 percent. The grain density of sandstone was $2.67 \pm 0.01 \text{ g/cm}^3$.

Two techniques were used to examine the fracture pattern created in the samples. The first technique was to cut 1-cm-thick sections perpendicular to the axis of the cylinder, impregnate them with epoxy, and polish. The second technique was to add a dye, fluorescein ($\text{C}_{20} \text{H}_{10} \text{Na}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$) to the borehole fluid. Immediately after sectioning, the cut sample was exposed to a black light to provide a detailed picture of the fracture pattern and the depth of fluid intrusion.

DISCUSSION OF RESULTS

Data from the tailored-pulse loading experiments indicate that the initiation phase of multiple fracture is dependent on the initial environment around the borehole, loading rate, and sample confinement. These effects are exhibited in Figures 2a and 2b which plot peak borehole pressure versus loading rate for quasi-dry and wet samples, respectively. Data for initially dry samples are superimposed with the quasi-dry data in Figure 2a. Bands estimating the threshold conditions for fracture and demarking the onset region of multiple fracturing from that of two fractures are also shown. The data shown here are for "sawtooth" pulses only. Examination of these figures illustrates the following important features: (1) threshold breakdown pressure increases with an increase in loading rate, (2) threshold breakdown pressure increases proportionately with sample confinement, (3) the onset loading rate for multiple fracturing tends to decrease for an increase in water content, (4) increase in confinement pressure reduces the onset loading rate for multiple fractures for quasi-dry samples (this may also be true for wet samples but tests have not yet been done to ascertain this), and (5) for dry samples where fluid intrusion is initially prevented, only two fractures occur regardless of the loading rate and confinement conditions.

The influence of the higher water content under confining pressure of 0.1 MPa is more marked at loading rates below about 30 MPa/ms, where multiple fractures still occur for wet samples, but only two fractures (i.e., typical-like hydrofractures) occur for quasi-dry samples. At higher loading rates the character of the multiple fracture initiation is very similar for both quasi-dry and wet samples. Furthermore, the number of fractures tends to increase with loading rate; about 10-12 fractures were initiated at a loading rate of 100 MPa/ms.

The threshold breakdown pressure dependence on loading rate is attributed to transient pore-pressure effects in a thin region around the borehole. For the quasi-dry samples the diffusion of fluid through the permeable borehole wall couples the response of the pore structure with the fluid flow through the pore space causing a pore pressure buildup. For wet samples, the action of the

- (a) Quasi-dry sample, ○ – 0.1 MPa and
● – 15 MPa confining pressure
Dry ◇ – 0.1 MPa and ◆ – 15 MPa confining pressure

- (b) Wet samples, ○ – 0.1 MPa, ● – 15 MPa,
and ■ – 25 MPa confining pressure

Figure 2. Fracture threshold characteristics for quasi-dry and wet Nugget sandstone.

borehole fluid displacing the pore fluid leads to a pore pressure buildup. Based on the characteristic diffusivity of the porous material-fluid combination, there exists a thin region around the borehole that may or may not (depending on loading rate and saturation of the sample) be in pressure equilibrium with the borehole pressure. The lower the loading rate, the more likely pressure equilibrium will exist. From this reasoning, we infer that the borehole pressure associated with the onset of fracture increases with loading rate, which is in accord with observed data. A more definitive discussion of pore-pressure influence on multiple fracture initiation is given by Swift and Kusubov⁶.

CONCLUSIONS

The observations described here demonstrate that the multiple fracturing process at intermediate loading rates is governed by fluid diffusion through the porous solid coupled to the structural deformation of the solid. The mechanism responsible for multiple fracturing appears to be the effect of transient pore-pressure buildup in the near vicinity of the borehole resulting from the diffusive intrusion of the borehole fluid. In the field, a select use of propellant can provide tailored pulses with loading rates comparable to those reported in this paper thus providing an alternative for present day techniques used to stimulate underground reservoirs.

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