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Creating a network of hydraulic fractures by cyclic pumping

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1. Introduction

The exploitation of tight sandstone oil and gas resources plays an important role in petroleum engineering. During the process of reservoir stimulation, how to create more fractures in tight sandstone reservoir becomes the key issue.

The state of loading conditions of rock material is determined by the failure type. Rock properties under cyclic stress are quite different from those under monotonic stress, especially for the failure features[1–5]. More micro-cracks are initiated in the rock specimen under cyclic loading[6–8] (as in the example shown in Fig. 1).

The failure of rock under cyclic stress loading is a very complicated process, and many current scholars have conducted research on it. Burdine[9] conducted uniaxial and tri-axial fatigue tests on the Berea sandstone in 1963, finding that sandstone specimens came to failure within 10^6 cycles under cyclic stress when the peak stress reached 74% of uniaxial compressive strength. Haimson and Kim[10] used two kinds of marble for fatigue tests, and the results showed that the compressive strength increased with augmented loading rate. Singh[11] conducted research on the fatigue and hardening characteristics of miscellaneous Australia sandstone. The research showed that the fatigue life of rock would increase with the decrease of stress amplitude and would follow the logarithmic decrement as the peak stress increased. Ishizuka's research[12] showed that rock strength decreased by 35–85% under cyclic stress within 10^5 cycles. Rock fatigue increased with augment of the cyclic loading frequency. The fatigue strength of the rocks in a humid environment would be reduced by 7% compared to that under a dry environment. Yamashita et al.[13] conducted a series of conventional triaxial compression tests and creep-fatigue tests both for soft and hard rock. The research also showed that the failure process and mechanism were very similar to each other for conventional triaxial and creep-fatigue tests.

During conventional reservoir stimulation, it often is taken for granted that hydraulic fracture fully interacts with natural fractures, which is an important requirement for initiation of complex fracture networks[14–16]. Otherwise, creating fracture networks will become a difficult job for a reservoir without many nature fractures. While, mechanical properties of rock under cyclic loading may provide us with some enlightenment of how hydraulic fracturing to stimulate the reservoir even without enough natural fractures. Reservoir rock is in the state of monotonic loading during hydraulic fracturing by conventional monotonic pumping, while it is under cyclic loading when fracturing by cyclic pumping. What, then, is the different performances between the two ways of fracturing?

As with hydraulic fracturing by cyclic pumping, there has been little technical research reported. In order to find an answer to the above question, it is necessary to design laboratory-scale experiments for further study.

2. Laboratory-scale experiments of hydraulic fracturing related to cyclic pumping

2.1. Specimen preparation

In laboratory-scale experiments of hydraulic fracturing related to cyclic pumping, the 300×300×600-mm cuboid concrete blocks are chosen as specimens in fracture simulation tests. The cement specimens are made of 40- to 80-mesh quartz sand and 32.5 R composite Portland cement mixed in the weight ratio of 1:1. The mortar is poured into a 300×300×600-mm square mold vessel. The manmade wellbore

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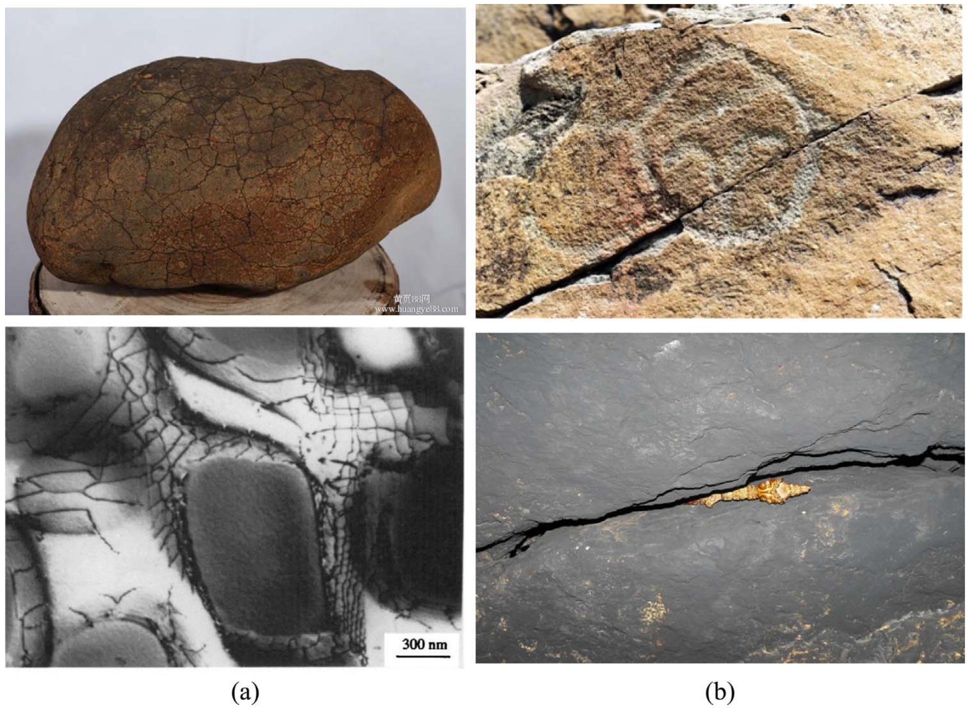

Fig. 1. The rock failure under (a) cyclic loading (thermal cyclic stress) and (b) monotonic loading.

is 20 mm in diameter and 250 mm in length. Before casting, the prepared wellbore then is fixed at one end of the square mold. The concrete blocks will be ready for use after fifteen days of curing time, as shown in Fig. 2. The properties of artificial cement-blocks provided by elementary mechanical tests are shown in Table 1.

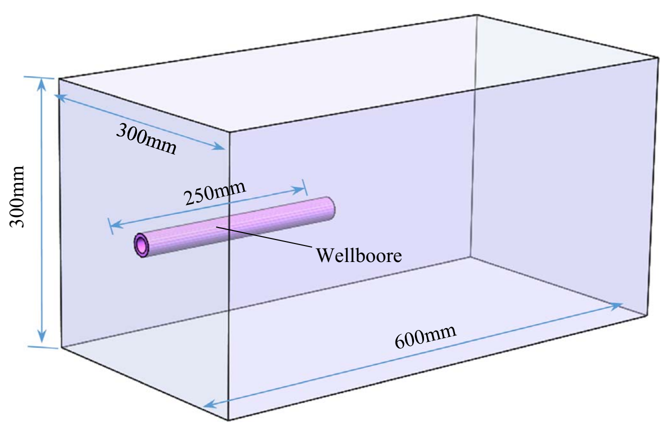

Fig. 2. The concrete specimen for laboratory fracturing experiment.

Table 1
Artificial cement blocks properties of specimens.

Property	Value
Density(g/cm^3)	2.11 ± 0.06
Uniaxial compression strength (MPa)	27.98 ± 1
Indirect tensile strength (MPa)	3.55 ± 0.2
Poisson's ratio	0.17
Elastic modulus, E (GPa)	24.6

2.2. Experimental equipment and plan

A series of laboratory-scale hydraulic fracturing experiments are conducted on the triaxial hydraulic-fracturing testing machine at the China University of Petroleum-Beijing, as shown in Fig. 3(a). The system consists of the JLB170-100 triaxial test stand, a two-chamber pump with a constant-speed or constant-pressure metering mode, a pneumatic control system, acoustic emission detectors and other supporting units, as seen in Fig. 3(b). As with triaxial flat jacks in the chamber, up to 20 MPa of compression stress can be provided in each axial direction in order to simulate the in-situ stress of underground formation. The injection pump can provide an injection pressure up to 150 MPa. The operation is as follows: the specimen is filled into the cavity chamber with triaxial stress loading σ_1-σ_2-σ_3 (where $\sigma_1 > \sigma_2 > \sigma_3$); then, the pump is started to inject the fracturing fluid mixed with red dye into the specimen through the pipeline, and the scheduled injections are maintained until one experiment is finished. In another method for using pump injection for fracturing, cyclic pumping, the entire fracturing process is completed by repeatedly starting and stopping the pump many times.

In order to probe the effectiveness of hydraulic fracturing by cyclic pumping and study the relevant factors of that, laboratory-scale experiments of hydraulic fracturing are conducted. Those experiments are divided into several groups for different research purposes as follows (as shown in Table 2 about the parameters of all experiments).

(1) Comparison of monotonic pumping and cyclic pumping in hydraulic fracturing is made to verify the effectiveness of cyclic pumping to create complex fracture networks.
(2) Determination of the influence of in-situ stress on the effect of hydraulic fracturing by cyclic pumping.
(3) Determination of the influence of different combinations of cycle number on hydraulic fracturing with regard to the complexity of fracture networks created by cyclic pumping.
(4) The influence of cyclic mode on the effect of cyclic pumping cycles