LABORATORY STUDY OF HYDROFRACTURING AND RELATED SEISMICITY

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Introduction

Hydraulic fracturing is one of the most effective methods for increasing the productivity of hydrocarbon fields. The method consists in a highly conductive fracture creation by pumping fluid into the well under pressure exceeding the strength of the rock and tectonic stress.

The fracturing is accompanied by seismic events which usually have small magnitudes - microseismic events. The microseismic event locations allow to get some understanding of the fracture orientations and sizes. At the same time, in the areas of intensive fracturing the seismicity started to increase significantly and dangerously. So, the problem of better understanding of the hydraulic fracturing relation with seismicity in surrounding rocks is important.

The results of laboratory experimental study of the hydraulic fracture propagation and related acoustic emission are presented. The experiments were carried out according to scaling analysis based on the radial model of the fracture [1]. All required geomechanical and hydrodynamical properties of a sample were derived from the scaling criteria.

Laboratory setup

The experimental setup differs from usual equipment designed for testing cores or cubic samples. Our setup is designed for work with samples of disk form which allows us to measure the pore pressure distribution along the sample together with acoustic emission (AE). The setup consists from two metal disks of 600 mm in diameter and 75 mm in thickness. A metal ring (height 74 mm, thickness 25 mm, the inner diameter 430 mm) is placed between the disks to form the pressure chamber with diameter 430 mm and height 66 mm. A rubber diaphragm is located between the upper disk and the pressure chamber, four thin chambers are located along the inner side of the ring (Fig.1). The stresses are applied by fluid injection into these side chambers and into the gap between the rubber diaphragm and the upper disk. The disks and the ring have holes used for mounting the pore fluid pressure sensors and acoustic emission sensors as well as for pumping fluids into or out of the model reservoir through the boreholes in the sample. Conductive strips are used to measure the fracture propagation rate.

Experiment on the hydraulic fracture propagation

The gypsum/cement mixture (proportion 9:1) with addition of 45% of water was used as the sample material (it was chosen on the basis of the scaling criteria). The sample was saturated by gypsum water solution. The hydraulic fractures were formed by mineral oil injection into the borehole in the sample under the constant rate 0.2 – 0.3 cm^3/sec. Some of the obtained fractures are shown in Fig.2. Usually, the fractures appeared on the sample surfaces. If we stop the fluid injection immediately after the injection pressure dropping, the fracture had a penny shape and did not appear on the sample surfaces.

The pore pressure variations (Fig.3) and acoustic emission were measured simultaneously. In the Fig.4, the positions of the AE sources are shown by the yellow marks together with time of the AE pulse emission. It can be seen, that the AE positions are related with the fracture position, time of the pulse emission corresponds to the fracture propagation.

It is remarkable, that we did not registered any AE outside the fracture. Comparison that fact with the results of the pore pressure measurements (Fig.3) and pore pressure diffusion numerical simulation (Fig.5) allows to suggest, that the pore pressure increase due to the viscous fluid injection is not enough to induce AE pulses at some distance from the borehole and from the fracture. It can be supposed, that when the injection fluid has the same viscosity as the fluid saturating the sample, the pressure increase could be sufficient to induce acoustic emission at some distance from the borehole and from the fracture. It will be studied in future experiments.

Conclusions

A series of the experiments on the hydraulic fracturing with simultaneous registration of acoustic emission (analogue of seismic events in real conditions) was conducted in agreement with scaling criteria.

Experiments have shown that the registration of acoustic emission pulses allows us to establish the trajectory of a hydraulic fracture in the laboratory experiment. The fracture propagation rate, estimated by acoustic emission (90 mm/s) is close to the rate in the special experiment with video recording of the moment when the crack reaches the surface (130 mm/s).

We did not get any AE outside the fracture. Comparison that fact with the results of the pore pressure measurements allows to suggest, that the pressure increase due to high viscous fluid injection is not enough to induce AE pulses at some distance from the borehole and the fracture. It was supposed, that if the injection fluid would have the same viscosity as the fluid saturating the sample, the pressure increase could be sufficient to induce acoustic emission at some distance from the borehole and from the fracture

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Publications

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Scaling criteria

According to the dimensionless complexes and to preserve the similarity of the model and nature, a sample material was chosen as gypsum and cement mixture in the ratio of 9:1. Water was added to the mixture (0.45 of the mixture mass). The gypsum mixture was dried, then saturated by gypsum water saturated solution.

$$N_\sigma = \sigma / \overline{E} \quad N_{K_1} = \frac{{K_{1c}}^2}{4 r_w \overline{E}^2} \quad N_\lambda = \frac{\sigma_{\max}}{\sigma_{\min}}$$

$$N_t = \frac{ti}{r_w^3} \quad N_{\overline{E}} = \frac{\overline{E} {r_w}^3}{\overline{\mu} i} \quad N_{K_l} = K_l \sqrt{\frac{r_w}{i}}$$

t - time, i - injection rate, r_w - wellbore radius, $\overline{E}$ - elastic modulus, $\overline{\mu}$ - fluid viscosity, K_l - leakoff coefficient, K_{1c} - critical stress intensity factor, σ - principal stresses.

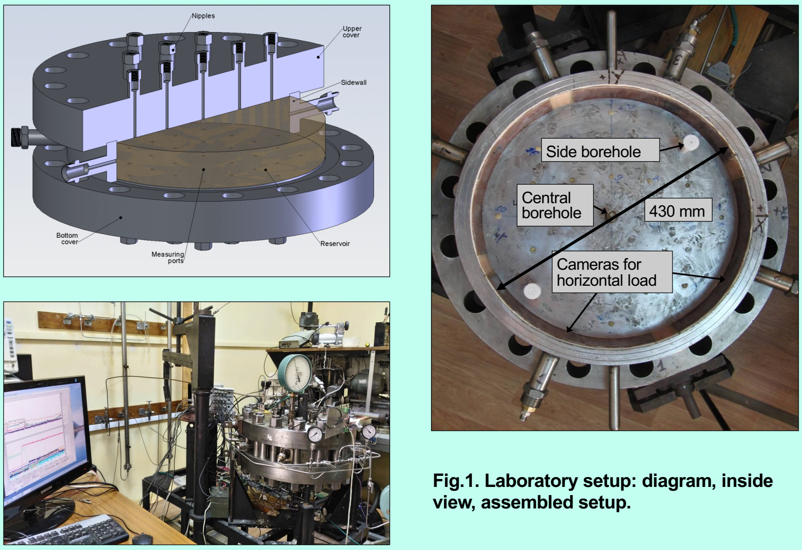

Fig.1. Laboratory setup: diagram, inside view, assembled setup.

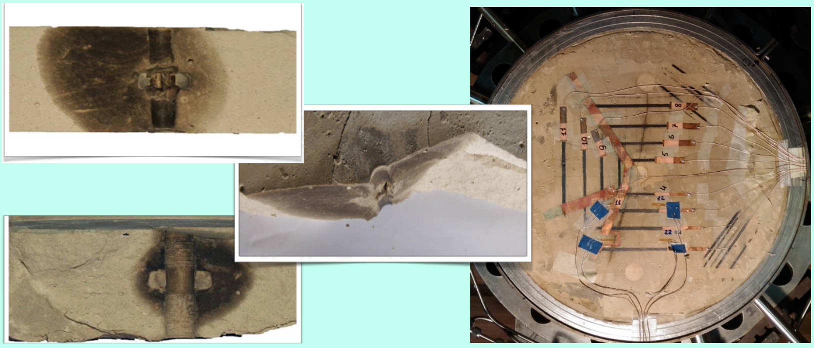

Fig.2. Hydraulic fractures in cross-section view (left) and samples top view after fracturing (right).

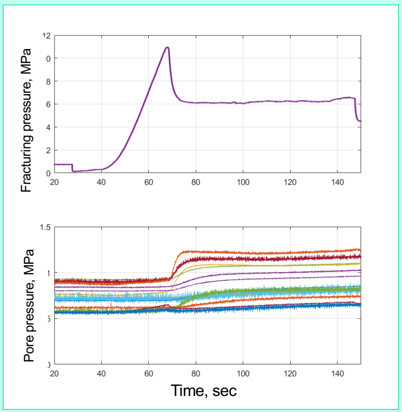

Fig.3. Fluid pressure variations during fracturing in the borehole and along the bottom side of the sample

Fig.4. Hydraulic fracture and acoustic emission

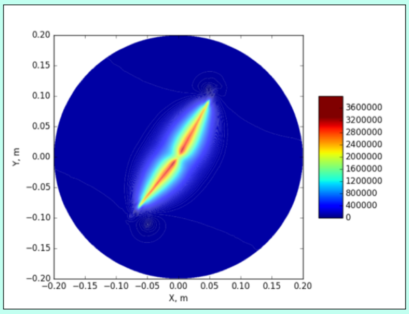

Fig.5. Numerical simulation of pore pressure diffusion during hydraulic fracturing