Measuring system to investigate geo- and gas-dynamic processes in hydraulic fracturing of coal seams

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Abstract. A measuring system has been developed for a test bench allowing the study of gas-dynamic processes in large-sized rock samples when performing hydraulic fracturing of a coal seam in a borehole model. This system provides collection of the data on pressure in a hydraulic fracturing device and loading of pneumatic jacks which create compressive stresses in the borehole zone, it also records acoustic emission during crack formation. An additional capability is implemented to measure the flow rate of gas supplied to sample through the holes on its side wall and pumped from the borehole.

1. Introduction
Methane contained in coal seams, or coalbed methane (CBM), is, on the one hand, a factor that provides additional challenges to coal seams development, and on the other hand, a valuable hydrocarbon resource, whose volumes increase exponentially with annual increases in coal production. The safe and effective development of gas-bearing coal seams depends on the degassing quality of the workings and seams worked or prepared to be worked (aka pre- and post-drainage i.e. removing methane from the seam in advance of or after mining). Application of underground directional drilling techniques, which have proved effective in pre-draining coal seams, with the degassing operations during about one year period in the working area will ensure up to 70% degree of coal seam degasification and safe coal extraction using cutting-edge high-performance stoping equipment [1]. Economic and technical feasibility of gas drainage depends on coal permeability and drilling density of degassing wells. The working radius of a borehole is generally limited to a few meters, which ultimately translates to extensive drilling and highly costly degassing operations. Among major and most effective ways to improve the degassing wells productivity (and thereby reducing their density) is multiple (interval-by-interval) hydraulic fracturing which initiates the formation of fractures with their subsequent filling with proppant material. Pre-drainage of stress-unrelieved coal beds in mine conditions using hydraulic fracturing has shown a 5-fold increase in methane captured in high-permeability (0.02–0.03 mD) coal seams and almost 180-fold increase for lower permeability seams [2]. Major drawbacks that presently hinder widespread implementation of this method is the deficiency in economically feasible and effective technical methodologies and devices for gas-dynamic logging of degassing boreholes and hence a lack of reliable gas emission prediction methods which is critical for controllable placement of degassing wells, i.e. locating the sites that require their higher / lower density.

2. Experimental setup and pressure test results
A specialized laboratory experimental system (test bench) was set up during implementation of the research project “Developing hydraulic fracturing technology for coal mining applications based on low-density proppants and robotic downhole equipment for higher efficiency of working gas-bearing coal seams and methane capture in them” with a purpose to investigate into geo-and gas-dynamic processes during intensive coal seam mining coupled with hydro-fracturing. The test-bench, which structurally is a metal frame (Figure 1, II) includes a physical model of a coal-bearing rock massif which basically includes: a device for simulating formation stresses; a gas supply system; test-bench control complex (Figure 1, I).

Let us take a closer look at the schematic representation of the experimental system. A degassing well 1 was drilled along the axis of the physical model of the coal-bearing massif 5. The coal bed stress state modeling was carried out using pneumatic jacks of horizontal 2 and vertical 3 action, connected to high-pressure hydraulic pumps 8, 11, 14 with tanks 7, 10, 13. The model pressure load is systematically measured with gauges 9, 12, 15, with strain gauges 6 installed in addition. The stand is equipped with measurement and recording system 16 and a gas station for investigation of the gas-dynamic processes (simulated disturbance of coal beds by mining activity) 17 with gas supply/drainage through ducts 4.

The physical model represents a sample of the coal-bearing massif (a parallelepiped with dimensions of 270×85×75 cm) prefabricated from crushed coal admixed with cement-sand composite which installed inside the metal frame of the stand. Cement, sand and dense brand “D” coal are mixed in the ratio 1:1:4. Figure 2 shows the photos of the test bench and the physical model of the coal-bearing massif. Upon the model hardening, wells are drilled into it with a diamond-tipped drilling tool.

During initiation of hydraulic fractures and their filling with proppant, the stress-strain state and the porosity/permeability characteristics gradually change in the physical model. The developed
experimental (R&D) model of a device for gas-dynamic logging has provided the interval-by-interval measurements of the coal-bearing massif permeability to gas [3]. The measuring system is organized on the basis of autonomous, GPS-synchronized SCOUT recorders (SKB ST, Samara). These recorders allow digitizing input signals with a minimum quantization interval (0.25 ms) and a time synchronization accuracy of 1 µs. Utilization of field versions of the recorders in the future will allow conducting a full-scale experiment without any modifications.

Figure 2. Test bench for the study of geo-and gas-dynamic processes when the hydraulic fracturing of coal seams is applied (a) and a model of the coal-bearing mass (b).

The model massif state monitoring included seismic emission records, using one-component GS-20DX and GS-ONE seismic sensors (vertical and horizontal). The SCOUT sensors were modified for recording output signals from the LH-412-250 bridge-type strain gauges in the frequency range 0–1500 Hz. A converter has been developed to connect the load cell to the recorder (Figure 3). The dynamic range of the output signal from the signal’s converter is controlled via the R1(Rg) resistor, so that converter’s output signal does not exceed 5V at the maximum pressure level (linear (active) region of the amplifier at the power supply voltage ± 7.2 V).

Figure 4a shows an oscillogram of the changes in the hydraulic system pressure while it is growing up to 20 MPa with the following rapid drop simulating hydraulic fracturing. The strain gauge output signal is converted to pressure using the linear coefficients $A$ and $B$ of the converter, which are determined during their calibration against model pressure gauge (manometer). For better representation of a three-channel pressure transmitter and the SCOUT data logger, they are shown in the photo (Figure 4b).

Figure 3. LH-412 and SCOUT converter circuit.
The test bench is equipped with a non-destructive testing and acoustic transmission systems, with
the source using reverse piezoelectric effect. An active piezoelectric element attached to the
exposed end of the rock bolt provides for the emitted signal transmission to the model. The rock bolt
contains a built-in screw for adjusting the force pressure received by the medium from the piezoceramic
emitter. This system can be used both for transmission and receiving elastic vibrations. A group of
emitters and receivers located at different points in the model form an observation system which allows
to follow the hydraulic fracture initiation and propagation. Let's evaluate the resolution capacity of the
acoustic control system of the test bench. The acoustic waves propagation velocity in the coal concrete
varies from 2500 to 5250 m/s. P-wave traveltine on the concrete along the maximum model length and
back is found to be not more than 1.5–2.0 ms. The physical limit of the acoustic monitoring resolution is
around 1⁄4λ, where λ is the wavelength of elastic oscillations. To achieve a resolution of 0.01 m, the
frequency of the acoustic signal must be at least 100 kHz. For reliable digitization of the harmonic signal
according to Kotel'mnikov’s theorem, the sampling period must be at least half of the signal period,
optimally, at least 1/10, i.e. achieving a resolution of 1 cm requires the data recording with a sampling
frequency of 1 MHz at a memory volume of at least 1500 points, which is available with most of modern
digital oscilloscopes.

![Figure 4. Resulting curve of the pressure converter data testing and recalculation (a),
and photo of the equipment (b).](image)

For future improvements to the model sample destruction process control, we consider it
advantageous to include in addition to acoustic transmission the method of isolating standing waves
from the noise field. The implementation of this method does not require additional changes in the
hardware part of the test bench.

3. Conclusions
A measuring system has been developed for the test bench designed to study the geo- and gas-
dynamic processes accompanying the hydraulic fracturing technology applications to working gassy
coal seams. The registration system enables control of pressures in the generated stresses in the near-
wellbore zone, as well as acoustic emission during hydraulic fractures initiation and propagation.
Additionally, a non-destructive acoustic control system with a frequency of probing signals of at least
100 kHz has been developed.

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