Borehole tool for studies in coalbed degasification wells

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Abstract. The paper presents a downhole tool designed for gas-dynamic research to be carried out in coalbed methane drainage holes. Structurally, the tool has a twin-packer design. The tool allows hydraulic fracturing, gas-dynamic investigations using indicator diagrams and pressure drop and recovery curves, and local destressing of coal.

A goal of gas-dynamic studies of degassing boreholes is to determine coalbed gas-saturation and permeability, to find vigorous gas evolution zones which make mining complicated. A problem of the studies is mismatch in conditions of gas escape into a borehole or an excavation. In case of interval borehole survey, exposed surface of coal bed is small. Due to stress concentration at the borehole boundaries, coal undergoes higher pressure than enclosing rock mass. Near-surface bed is damaged and partially degassed during the process of drilling. In order to increase the accuracy of the studies we suggest conducting them in coalbed hydraulic fracturing interval along with the radially symmetric loading of the borehole walls. The loading provides hydraulic fracturing crack opening, so it is possible to measure gas recovery of the coalbed, when degassing area surface free from stress is enlarged. After a degassing borehole interval is sealed, the crack opens, which provides the opportunity to study gas recovery from the beginning of degassing surface formation out of drilling influence zone.

This article describes methodological and technical solutions providing the interval gas-dynamic studies along with the regulated coalbed destressing. On the basis of the solutions we have developed a borehole tool equipped with embedded system of travel along the borehole and flexible high-pressure hoses connecting the borehole equipment with the mine working equipment (pump, remote control, measuring system). The tool is capable of performing the following technological operations and measurements:

— sealing of an uncased borehole interval, supplement of a working agent (compressed nitrogen, water-in-oil emulsion) under pressure or drawing off formation fluids controlling their pressure, temperature and volume discharge;
— hydraulic fracturing of coalbed by the working agent and measuring of lock-up pressure $P_s$ and reopening $P_r$ of the created crack;
— radially symmetric loading of hydraulic fracturing interval through plaster cover preventing the contact of working fluid and rock mass;
— increase or decrease of pressure in the isolated interval of the borehole and the following measurement of decline curve or pressure $P(t)$ recovery curve;
— determination of indicator diagram (ID)—dependence of pressure in the borehole isolated interval on formation fluid (gas, water) volume charge $Q$. 
The tool scheme is shown in Figure 1.

Figure 1. Borehole tool for gas-dynamic studies: 1—packer sleeve, fixed at hydraulic-cylinder rod; 2—drainage layer; 3—injection zone; 4—packer sleeve, fixed at hydraulic-cylinder body; 5—hydraulic-cylinder rod; 6—hydraulic-cylinder piston; 7—hydraulic cylinder; 8—gas spring; X—fixed sleeve end; •—movable end; L1–L3—high-pressure hoses.

The tool is made accordingly to the scheme of a double packer with controllable interval between cord-reinforced air bags 1 and 4 (Figure 1). Regulation of injection zone 3 is performed with the help of hydraulic cylinder 7. There is an immovable sleeve end 4 fixed to its body. Long air bag 1 is fixed on polished rod 5 of the hydraulic cylinder. Sealed movable ends of both packer sleeves shift along the rod. The main technical characteristics of the tool:

| Characteristic                              | Value         |
|--------------------------------------------|---------------|
| Tool length                                | 2870 mm       |
| Tool diameter                              | 60 mm         |
| Tool mass                                  | 12 kg         |
| Hydraulic fracturing pressure              | Up to 18 MPa  |
| Borehole wall loading pressure by packer   | Up to 26 MPA  |
| Borehole diameter                          | 76–105 mm     |
| Borehole length                            | Up to 1000 m  |
| Borehole orientation                       | No limit      |
| Continuous work duration                   | No limit      |
| Travel speed in borehole                   | Up to 100 m/h |

The tool works in three modes: transition in the borehole, hydraulic fracturing, crack opening by the packer sleeve and gas-dynamic study. In the transition mode the tool works according to the following scheme. The working agent under pressure is supplied to the packer sleeve 4 and hydraulic cylinder 7 through the high-pressure hose L2. Under the influence of the working agent pressure the packer sleeve 4 is inflated and adherent to the rock mass. In this state the packer sleeve works as an anchor for the cylinder body 7. The working agent presses on the piston 6 and moves it with the hydraulic cylinder rod 5 into the borehole, pulling up the packer sleeve 1 and high-pressure hoses L1–L3. Then, through the high-pressure hose L1 the working agent is supplied into the packer sleeve 1, which inflates and, therefore, contacts the borehole walls. Through the line L2 the packer sleeve 2 pressure is transferred into the drain system. The sleeve 2 does not have the contact with the ground. The hydraulic cylinder gas spring 8 influences the sleeve 2 so that relatively to the fixed rod the sleeve moves into the borehole.

In case of hydraulic fracturing the tool works in another way. First, the working agent is supplied into the packer sleeve 2, and then, into two sleeves 1, 2 under the pressure of 2–4 MPa. This order of operations provides the opportunity to gain the maximum injection distance. Next, the working agent is supplied into two sleeves, and through the pressure reducing valve and high-pressure hose L3 the working agent is pumped into hydraulic fracturing interval, until a crack is formed in the rock (Figure 2a). The valve helps to maintain the pressure ratio 4–6 MPa between the packers and the injection interval. These conditions are sufficient to keep the fractured interval sealed. A sensor measures pressure in high-pressure hose L3. On the basis of its measurements we determine $P_s$ and $P_r$ pressures, which are used to estimate the rock mass unloading and area of its degassing.
Figure 2. Scheme of the tool working in different modes: hydraulic fracturing (a) and gas-dynamic research (b): 1—hydraulic fracturing crack; 2—area of the crack opening by the packer sleeve; 3—gas delivery into the injection interval.

In the gas-dynamic research the tool works in the following way. At first the tool is placed into the borehole so that a part of the long packer sleeve 1, coated with drainage layer, takes place in the interval of the hydraulic fracturing crack (Figure 2b). After that, under 2–4 MPa pressure the working agent is supplied into the packer sleeve 1, then—into two sleeves 1, 2. Thus, by preserving this order we get the minimal injection interval length.

The tool provides the opportunity to conduct gas-dynamic research of the coalbed zone in steady (indicator diagrams ID) and non-steady (decline and recovery pressure curves) states. Implementation of different methods in the tool increases the measuring accuracy of permeability and storage properties of a coalbed. Gas-dynamic research conducted by any of the mentioned methods is carried out if there is a hydraulic fracturing crack opening. To cause the opening we set pressure bigger than \( P_r \) in packer envelope 1. The depth of the crack opening is determined by the methods presented in the work \[1\].

Data processing is performed in the following way:

— in accordance with the measurements plot the dependence \(\frac{P_0 - P}{Q_g}\) on gas output flow \(Q_g\), where \(P\) — pressure in injection interval; \(P_0\) — formation pressure defined by pressure stabilization in closed injection interval when \(Q_g = 0\);

— approximate the curve by dependence \(\frac{P_0^2 - P^2}{Q_g} = a + bQ_g\) and determine \(a\) and \(b\) coefficient using the ordinary least squares method;

— calculate the expected maximum gas rate when the borehole is set with degassing system of a mine by the formula \(Q_g^{\text{max}} = \sqrt{a^2 + 4b(P_0^2 - P_V^2) - a} / 2b\), where \(P_V\) — pressure in the mine degassing system;

— calculate the averaged gas formation pressure \(\bar{P}_0\) using the formula

\[
\bar{P}_0 = \frac{1}{N} \sum_{n=1}^{N} \sqrt{P_n^2 + aQ_{s,n} + bQ_{s,n}^2}.
\]  \( (1) \)

If the obtained formation pressure differs from the value used for the indicator curve construction, then, the averaged pressure calculated from the formula \( (1) \) is used for the second data processing accordingly with the mentioned algorithm.
The measurements of the decline pressure curve are processed by the following simplified
technique:
— with the help of the conducted research determine the gas flow before the research and schedule
a dependency graph of the square of the pressure in the injection interval on the common logarithm of
time \( t \), counted in seconds from the pressure recovery;
— approximate the graph by the dependence \( P^2 = \gamma + \beta \lg t \), where \( \gamma \) and \( \beta \) are the
approximation coefficients;
— using the obtained value \( \beta \) calculate the gas permeability of the coal bed using the formula
\[
\varepsilon_g = \frac{0.023 q T_0 Z_0 P_f}{\pi \beta T_s},
\]
where \( q \)— gas flow rate before the research conducted by decline pressure
curve, \( m^3/s \); \( T_0 \) — gas temperature in the bed, K; \( T_s = 293 \) K; \( Z_0 \)— methane compression coefficient
in case of bed’s temperature and pressure;
— using the well-known gas dynamic viscosity in beds \( \mu_0 \) calculate product of horizontal
permeability and net pay thickness on gas transferred to injection interval’s length unit \( h \)
\[
k_g = \frac{\varepsilon_g \mu_0}{h}.
\]

Data can be processed with the other improved methods not discussed in the article. It should be
pointed out that the coalbed can contain methane in bound and unbound states. When the bed is
being drilled the unbound gas goes into the low-pressure zone and the bound gas diffuses in the
filter volume of the coalbed. As a result there are two areas on the pressure recovery curve; each of
them is studied separately. As the diffusion process is relatively slow, the test can take from several
hours up to several days, which is not possible in case of a borehole study. The alternative is the
assessment of the unbound methane gas recovery. In this case total gas content of the coal bed can
be determined by the estimation of the unbound and bound methane relations in the bed, for
example, by the methods mentioned in the paper [2].

Conclusion
We have developed a tool providing the opportunity to conduct the gas-dynamic research of a coalbed
in steady and non-steady states using indicator diagrams, pressure decline curves and pressure
recovery curves. The tool ability to combine different techniques increases the validity of the
permeability and the storage capacity of a coalbed, including its formation pressure, gas permeability
and expected rate of degassing boreholes.

A distinctive feature of the tool is its capability to conduct research at a distance from a borehole
collar. For this purpose the tool is equipped with embedded travel system in uncased extended
borehole of any orientation. The tool is capable of conducting research being several hundred meters
away from the mine working.

The tool provides hydraulic fracturing of a coalbed by working agent and gas-dynamic research
with the formation of a crack due to radially symmetric loading of borehole walls. Local loading of a
coalbed increases the accuracy of the research into coal gas content and makes it possible to study gas
recovery depending on degassing surface area free from pressure.

References
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