Determination of filtration properties of coal seams during mine measurements

O V Tailakov, E A Utkaev and M P Makeev
Institute of Coal, FRC CCC SB RAS, 10 Leningradskiy ave., Kemerovo, 650065, Russia
E-mail: tailakov@uglemetan.ru

Abstract. A brief analytical review about the issue status on monitoring the filtration properties changes of a coal rock massif under the influence of hydrodynamic impact, undertaken with the purpose to stimulate gas recovery from coal seams, is given. The necessity of improving methods and equipment used to determine the near borehole zone permeability is substantiated. The design features of a device designed to connect an electronic pressure gauge to a borehole to provide continuous monitoring of pressure fluctuation in horizontal degasification wells during injection tests are presented. The results of coal seams permeability measuring undertaken in conditions of Kuzbass mines are presented and discussed.

1. Introduction
At present, the methods and means of hydrodynamic impact for improved degasification efficiency of coal seams during coal mining, as well as forcoalbed methane (CBM) recovery from an intact coal rock massif find an expanding application. Thus, in [1], a method for methane recovery from an unloaded coal seam using a separate production zone located between the fractures is presented, and the estimate of filtration properties increase in unloaded coal seams of this zone, which is subjected to vibrational hydrotherapy, is undertaken. A methodology has been developed and justified for determining a sufficient number of unloading-compression cycles during hydraulic stimulation of gas discharge from the intact coal rock massif.

The obtained results can be used to justify technological solutions for methane recovery from a separate production zone located between fissures formed by the hydraulic fracturing. For the coal seams hydraulic fracturing undertaken for degasification purpose and subsequent methane production, a specialized kit was developed in [2, 5], including a drilling rig, slotting machines, packer devices, and installations for water injecting into the formation. The kit testing in laboratory and in mine conditions demonstrated the developed equipment high efficiency in reducing in-situ gas content of coal seams. In [3], the concept of anthropogenic impact on a thermodynamically nonequilibrium coal rock massif to boost the methane desorption was substantiated.

It is shown that coal seams degas efficiency increase is ensured by the combined application of active and passive methods, the higher permeability of coal and accompanied transition of methane from the sorption space to the filtration one. At the same time, the effect of coal rock massif self-organization under the controled actions coordinated with its own structures can be used to create new effective technologies for gas recovery from coal deposits.
In [4], a lab setting and a technique for studying methane emission intensification from coal samples under a wave action were developed to increase gas desorption. The problems of coalbed methane genesis and promising options for their solution were considered in [6], where the first established physical phenomena occurring in methane-bearing coals are presented, which make it possible to predict ordinary and sudden gas outbursts in mine workings.

A scientifically based classification of in-mine and surface degasification methods for coal mines is given. In [7], the issues of ensuring high-performance and safe operation of gas-bearing coal deposits by the underground method were investigated, the main factors affecting the intensity of gas emissions into mine workings and boreholes as well as indicators of coal gas discharge were determined, the criteria, measures and recommendations for the efficient methane recovery from coal seams by degasification technique were substantiated.

In [8–11], the methodology for degasification technology selection and methodological recommendations on the adoption of rational technological schemes for coal seams by strata degasification are substantiated, based on the experimental determination of basic properties and conditions of the coal-gas bearing massif aimed for intensive mining. A model has been developed and investigated that describes coal rock massif filtration properties and takes into account gas-bearing formation satellites to determine a zone radius for hydro treatment. It is proposed to consider a gas collector in [12] as part of the roof and soil displacement zone of the worked out coal seam, within which the porosity and permeability parameters of rocks differ from the corresponding parameters in the coal rock massif outside a coal workings zone of influence. It was shown that in gas reservoir, distribution of gas occurs unevenly also depending on the initial porosity of rocks and the depth of rock layers settings.

In [13], the proppant feed into a coal seam after hydraulic fracturing to maintain crack banks stability over time was considered. It is shown that proppant grinding and its diagenesis are the most common damaging mechanisms encountered in the process of hydraulic fracturing.

In [14], methods for studying coal seams geology, principles for methane-coal strata development, test methods for coal seams filtration properties determination based on injection and slug tests application are presented in detail. The mathematical model of coal seam hydraulic fracturing, describing this process as the propagation of pressure pulses, was developed and substantiated in [15]. Known methods for permeability assessment in mine conditions, which are based on the analysis of data obtained in gas recording process considering pressure restoration or its drop in the borehole, can take a fairly long period of time depending on the coal seam filtration properties [16].

It should be noted that despite the successful experience in applying technologies and approaches to estimate filtration properties of coal seams and enclosing strata it is necessary to improve methods and means for determining changes in their permeability before and after applying measures aimed to boost the production rates of strata degas boreholes. Studies to determine the filtration characteristics of the bottom hole zone of a well drilled from mine workings are an important step to assess their technical conditions and to develop recommendations for their future operation.

During gassy coal seams mining, the methane content in workings is one of the main factors limiting the load on the longwall face and the construction rate of development workings. With increasing depth of mining operations, the gas content in excavation sites increases. Moreover, the maximum possible amount of air supply does not always ensure the required methane content in mine atmosphere, and thus, the improved efficiency of coal seams degasification is an essential factor to ensure the mining work safety.

2. Main part

To determine the filtration properties of coal seams in in-situ mine conditions, a technological scheme and an injection test procedure [17-19] have been proposed, developed and justified, affording to study their changes in the near-borehole zone (figure 1). The set of equipment includes an in-depth electronic pressure gauge, a high-pressure flask, a mechanical pressure gauge, a pump station and high-pressure hoses.
The fluid is fed into a horizontal borehole by a pumping station designed to pump working fluid into the hydraulic system of longwall shearsers and mechanized supports in mines of any category by gas and dust. The connection of pumping equipment to the well head is done by using high-pressure hoses.

The fluid supply to the investigated well is performed at a constant flow rate [14]:

\[
q_{inj} = \frac{k_W h P_{max}^{Surf}}{70.65 \mu B_W \ln(2.25 t_D e^{2s})},
\]

where \( k_W \) is the permeability coefficient \((m^2)\); \( h \) is the total thickness of coal seams \((m)\); \( P_{max}^{Surf} \) - maximum pressure supplied to the wellhead, \( H/m^2 \); \( \mu \) - coefficient of dynamic viscosity of water, \( kgf \cdot s / m^2 \); \( B_W \) - compressibility factor; \( t_D \) - the dimensionless injection time.

In this case, the fluid injection time is determined as follows:

\[
t_{inj} = 5.2 \cdot t_{Dws},
\]

where \( t_{Dws} \) - dimensionless time of the final period of waiting for the pressure drop in the borehole:

\[
t_{Dws} = \frac{17 \cdot 10^4 C e^{0.14 S}}{kh \left( \frac{k}{\mu} \right)}.
\]

Here \( C \) is the accumulation coefficient; \( S \) is a skin factor; \( k \) is the permeability coefficient. Estimated pressure drop time is:

\[
t_{exp} = 2 \cdot t_{inj}.
\]
Based on the fact that a mine pump productivity is high, the injection time is adjusted depending on pressure at which hydraulic fracturing can occur. At the end of the period of fluid injection into the formation, the borehole is hermetically sealed and pressure drops are recorded during the estimated time.

To connect the pressure sensor to the working fluid injection system, a modernized flask was developed and manufactured (figure 2), which is a high pressure sleeve (2) with a metal wrap (EN 856 4SH) with an outer diameter of 68.1 mm, two plugs (3) with a welded quick disconnect fitting (1). The mass of the flask is about 9.5 kg, which is significantly less than the previous version, which was made of drill pipes. The flask sleeve consists of an inner layer (oil-resistant synthetic rubber), reinforcement (four layers of steel wire of a spiral winding) and an outer layer (synthetic, abrasion resistant rubber).

At the end of the waiting period, the pressure sensor is removed to analyze and interpret the data. Programming of an electronic stand-alone pressure gauge and data export is performed using the MPSWin software product, in which the time between measurements, the duration of measurements, as well as the ratio of the number of pressure points and temperature taken, are set.

The manometer is programmed directly when it is connected to a personal computer. Data is imported and exported using the monitor-probe interface (MPI) via the RS232 port. Next, the final data processing is carried out, as a result of which the permeability, skin factor and capacitance coefficient are determined.

Upon the study results, pressure fluctuation during the time of injection and expectation of a fluid pressure drop are recorded in the borehole (figure 3). Based on the processing and interpretation of these data, the permeability $k_x = 34.33$ mD, $k_y = 2.00$ mD, $k_z = 5.06$ mD and the skin factor of 0.76 were determined.

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3. Conclusion

Thus, the possibility of measuring coal seams permeability in in-situ conditions of coal mines by conducting injection tests directly in horizontal degas boreholes drilled from mine workings is shown. At the same time, the use of a modernized version of a high-pressure flask with a reduced weight significantly reduces labor costs and time for transportation of the equipment set to the place of measurements and provides coal seams filtration properties determination at a fluid injection pressure of up to 12 MPa. In the future, it is assumed that the developed approach and the equipment set will be used to monitor the effectiveness of measures for a controlled roof landing under hydrodynamic effects.

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