Development of experimental plant for investigation of coal adsorptive capacity using methane

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Abstract. A thermostatic plant for studying the adsorptive capacity and permeability of coal core was developed. The plant design allows to saturate coal with methane and to filter gas at various values of axial and lateral compression of the sample. The use of an automated system for recording differential pressure and gas volumes in the inlet and outlet tanks eliminates the need for manual control, which is especially important during long-term testing of low-permeable coals.

1. Introduction
The increasing rates and depth of mining gassy coal seams in underground mines require timely and rapid methane capture to reduce its concentration in the coal seam. Gas recovery levels sufficient for safe stoping operations can be achieved only with the degasification schemes designed on the basis of the geological and physical modeling of a gassy coal massif and availability of reliable data on its properties. Although determinations of coal permeability, its saturation with gas, adsorption capacity, and other critical in-situ parameters may yield reliable results of the desired values, they do not characterize their dependence on pore and rock pressure [1, 2], temperature, etc. Therefore, the in-depth laboratory studies of these dependencies will be required prior to creating a realistic model of a coal seam.

This paper presents a laboratory setup (system) for studying coal permeability and adsorption capacity by simulating methane filtration within it. The automated data collection system allows avoiding continuous observations of the experiments progress. The experimental system is designed to obtain dependences of the studied parameters on the rock and gas pressures and temperature, i.e. the information required for planning the methane control and degasification operations in coal mines.

2. Overview of methods for permeability measurements of rock samples
Laboratory studies of permeability are usually based on cylindrical samples with a length of 60–100 mm and 30–50 mm in diameter. In determinations of gas permeability, the correction for gas slip effect along the pore channel wall (the Klinkenberg effect) is taken into account [3]. The principle approaches used herewith are:

Stationary (steady-state) method [4]. The studies are conducted after the filtration process is established along the axis of the cylindrical sample. Its side walls are sealed, and at the end faces pressures in the filtering agent (liquid, gas) are kept constant, whose values differ from each other and are designated as $P_{in}$ and $P_{out}$ ($P_{in} > P_{out}$) (Figure 1a) [5, 6]. In the entire sample, the filtration rate vectors are believed to be equal in values and perpendicular to its end faces. The value of permeability
$k$ is determined by Darcy’s law that describes the flow of a fluid through a porous medium using the equation:

$$k = \frac{\mu LG}{S(P_{in} - P_{out})},$$

(1)

where $\mu$ is dynamic viscosity of fluid; $L$ is sample length; $S$ is cross-sectional area of the sample; and $G$ is flow rate.

**Figure 1.** Schemes for permeability measurements: (a) by the stationary method; (b) by the pore pressure oscillation method; (c) by the non-stationary method.

*Pore pressure oscillation method.* When permeability is determined using the oscillation method, the fluid pressure at the input end of the sample changes according to the periodic law (Figure 1b). Permeability of the samples is calculated from a relationship between the amplitudes and phase shifts of fluid pressure oscillations in the inlet and outlet tanks [7]. A major advantage of this method is a relatively short duration of the experiment. Its modifications allow to determine the sample’s porosity in addition to permeability. This method allows measurements at the fluid pore pressure of about 1 MPa.

*Method of attenuating pressure pulses.* The pulse decay method, or non-stationary method was developed by Brace and colleagues [8] for measuring permeability using procedures described below. The input and output ends of the sample isolated on the side surface are connected to the closed-loop tanks (Figure 1c). At the initial moment, the fluid pressures in the sample in both tanks are uniform and equal $P_0$. Then, the gas pressure is increased stepwise in small increments $\Delta P \ll P_0$ in the inlet tank. Driven by the pressure differentiation between the sample ends, the fluid moves through the sample. As a result, the fluid pressure in the inlet tank decreases, whereas in the outlet tank it rises to reach a certain equilibrium value. The obtained pressure-time records in both tanks ($P_{in}$ and $P_{out}$) are used to determine the value of permeability.
3. Scheme of laboratory setup and experimental technique

A schematic diagram of the developed laboratory setup for implementation of the considered methods is shown in Figure 2.

![Figure 2. Schematic diagram of the laboratory setup.](image)

The rock sample is placed in the chamber (block A). The sample is exposed to axial and lateral loads created by the compressed nitrogen pressure (block B). The gases (block G) that can be used as a filtering agent in the system are: methane, helium, and carbon dioxide.

The design of block A permits to conduct the experiments in a wide range of differential and average (pore) pressures of gas in the sample, its axial and lateral compression and temperatures simulating varied conditions in the carbonaceous rock massif. Gas filtration is carried out using small-volume A1 and A2 cylinders connected to the chamber’s inlet and outlet. Cylinder A2 is not involved during the study of the samples’ permeability by the stationary method, while the chamber outlet is connected to a volumetric flask filled with nontransparent liquid [9]. The fluid volume displaced by the gas is inferred from its column height using electronic optical system.

When conducting the research based on the pressure pulse oscillation and attenuation methods, the cylinders in addition can be coupled as batteries or connected to an extra line to supply controlled portions of the compressed gas. Measurements of the methane-coal adsorption are carried out using the volumetric method [10].

The main elements of the experimental laboratory system shown in Figure 3 include filtration chamber representing a modernized Hassler cell (maximum pressure in the cavity: 30 MPa; the length in complete assembly: 200 mm; width: 60 mm (Figure 3c). The compact design allows the camera to be placed in a small thermostat (Figure 3b).

The sample is exposed to lateral and axial compression using B1, B2 cylinders (Figures 2 and 3d) with compressed nitrogen. The pressure control (within a range from 0.01 to 15 MPa) is carried out using electronic pressure gauges. After the required pressure level is reached, the pressurized gas lines are shut-off by the valves.

Special small-volume (0.8 to 5.5 L) Kovea KT-2909 brand A1 and A2 cylinders (South Korea) were used for the system supply with methane (Figure 2). These have a threaded connection according to the MAPP US standard, which ensures reliable connection to the filtration line and allows maintaining a pressure differential from 0.001 to 2 MPa. The cylinders are filled with gas from a large-volume tanker trough a special manifold (Figure 3a).
Figure 3. The main elements of the experimental laboratory system for permeability measurements and study of adsorption properties of coal: (a) methane tanker; (b) thermostat; (c) elements of the filtration chamber; (d) pneumatic system for sample compression by external pressure.

The volumes of gas filtered with the use of the stationary method for permeability measurements are derived from variations in the height of the colored liquid column in a special volumetric flask and registered by the Arduino pressure sensor pad with subsequent time history recording in specialized software.

The study based on the pressure oscillation and pulse attenuation methods involved the pressure (or pressure differential) recording by a highly sensitive SITRANS P sensor (SIEMENS, Germany) with the obtained values transmitted to a computer.

4. Conclusions
A laboratory setup has been developed to study the permeability and sorption capacity of coal under rock pressure up to 30 MPa.

Its design enables an independent control of differential and average gas pressures in the sample.
The study of adsorption capacity of coal using the stationary and non-stationary methods using methane, helium and carbon dioxide as filtering agents, can be supplemented with volumetric measurements of methane-coal absorption.

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