Use of the permeability test of Carboniferous rocks in the underground coal mines located in the Upper Silesian Coal Basin

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Abstract

Carboniferous rock permeability tests can be used both for documenting hydrogeological and gas conditions, as well as for predicting the possibility of pre-exploitation demethanation of seams and rock mass surrounding mining excavations. The article describes the research process of rarely performed non-destructive profiling of permeability of hard rocks in different directions (x, y, z) using a PDPK-400 permeameter created by Micrometrics. The solution can be applied in mining hydrogeology, and in particular in the assessment of the water hazard in mines located close to reservoirs in flooded mine, evaluation of water filtration through safety pillars and in determining zones with increased permeability, among others for the migration of mine gases to demethanize the deposits, e.g. through holes from the surface.

Keywords: permeability, hydrogeological properties, USCB, rock mass, rocks

Introduction

Extraction of hard coal generates various interdependent hydrogeological phenomena. The restructuring of hard coal mining conducted since 1990 in USCB have led to the abandoning of some mines and coexistence of active and flooded mines. Mining activity negatively affects on water environment and results in drainage of aquifers and discharge of large amounts of contaminated minewater to surface watercourses. Lack of activities aimed at dewatering of mine workings of decommissioned mines causes them to be filled by the water from the natural inflow. The water level in the flooded excavations increases gradually until a hydrodynamic equilibrium is obtained with the aquifers in the surrounding Carboniferous rock mass. Conditions for the formation of hydrodynamic equilibrium may occur in border regions with active mines as a result of filtration of water that leaks or escapes from the decommissioned mine's reservoirs to the workings of an active mine. In the area between the flooded and active mines, there are conditions for hazards related to the flow and accumulation of water and gases in the rock mass. This may determine the possibility of a water hazard (disruption of the safety and effect pillars) and methane hazard in active mines and surfaces (pushing methane out of flooded excavations). Mining exploitation carried out at ever greater depths records lower values of water inflow to mine workings, but increases methane emission from coal seams, which is associated with known regularities in the geological structure of USCB and variability of porosity. The methane capture in the CBM, CMM and AMM process is increasingly difficult to plan due to the constantly decreasing porosity and permeability of rocks in the vertical profile. The difficulty in determining the conditions of water and gas circulation in mining excavations and rock mass and the difficulty in establishing plans for draining the rock mass and its demethanation is often caused by the lack of knowledge of the variability of the rock and rock mass permeability distribution in the vertical profile.

The permeability of rocks is relatively rarely investigated in mining hydrogeology in the areas of hard coal mines. The tests are carried out on rock material taken from mine workings as solid samples or on cores from holes made at the bottom of the mine. Commonly used methods of researching hard rocks include specially prepared rock samples, tested in one direction, generally in a direction parallel to the axis of the core sample and perpendicular to the stratification. Such

standard tests allow obtaining the test result at least by an order of magnitude smaller than in the case of a test made perpendicular to the core axis and parallel to the bedding of rocks. The test result is obtained in a time-consuming manner and after preparation of the core and selection of test samples. In addition, it replicates the filtration process, which is closer to the inter-layer filtration process. The research process of profiling the filtration coefficient in the direction perpendicular to the axis of the core sample, i.e. parallel to the stratification using the PDPK-400 device created by Micrometric, is described below.

Characteristics of the test method with the application of PDPK-400 permeameter

The PDPK-400 permeameter is used for non-destructive drill core permeability profiling. This device gives the possibility of precise measurement of the permeability of one-meter rock samples cut from the core perpendicular to its axis, in two planes, in the XY system (photo 1A). The markings are carried out using gases, mainly nitrogen class 5.0 or 6.0. The device allows to determine the heterogeneity of samples thanks to the tested filtration properties, in order to identify the ranges of high and low permeability of the examined rock layers. The device is equipped with a built-in sensor that indicates the exact location of the measurement sites, and also has the option of selecting any interval of the core to be tested and planning frequency of measurements.The test is carried out with a wide measurement range from 0.001 mD to 30 D. The time of determination of the permeability at one measuring point varies from 2 to 35 seconds. The permeameter enables testing of drill cores of various diameters, but not less than 2.5 cm, and of any length of the drill core tested in measuring cycles from 2.5 cm to 3 m in one measuring cycle. It conducts measurements in an extremely precise, fast and efficient manner, giving the possibility of non-destructive profiling of permeability of drilling cores in the direction of parallel flow to the stagnation. The device also allows to conduct tests of permeability on individual samples (2.5-20 cm) cut out from the core or on rectangular cube samples used in geomechanical studies with height or thickness below 20 cm. Then the measurements are made in three planes, perpendicular to the axis of the sample in the XY system and parallel to the axis in the Z-system (photo 1B), i.e. in a parallel and perpendicular direction to the strangulation.

The device is fully integrated with the control unit equipped with the PROPERM software, giving the possibility of the current registration of the test. Based on the obtained data, it is possible to create graphs of variability of permeability as a function of depth, taking into account the entire lithostratigraphic profile of drilled layers and determination of fragments with increased and reduced permeability.

The principle of measuring permeability is to determine the time curve of nitrogen pressure drop in the main tank, which is connected to the probe injecting the

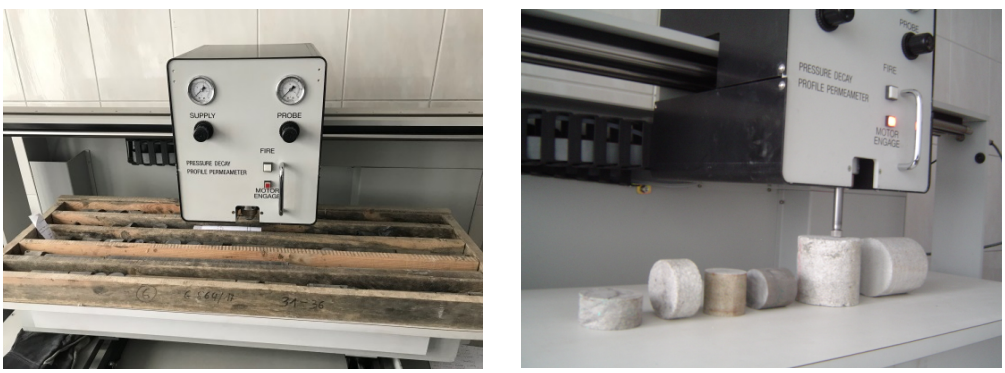

Photo 1. *PDPK-400 permeameter A – profiling of permeability on rock cores; B – testing of individual rock samples*

medium into the sample under test. The permeameter allows measurements of sample permeability including corrections for the gas slip effect (Klinkenberg correction), so that even at low speeds, the gas flowing through the porous rock behaves in accordance with Darcy's law.

In the case of samples where intense gas flows occur in fissures with high permeability and small width, linear flow velocities are characterized by high values. Under these conditions, the flow becomes turbulent and there is additional flow resistance due to inertia effects. Permeability measurements performed by the PDPK 400 can therefore also be carried out under conditions of high inertia of the sample, even with relatively low differences in applied pressures. Hence, the analysis includes the Forchheimer correction. The inertial resistance virtually disappears for samples with a permeability <0.1 mD for initial pressures <10 psig.

Possibilities of application of permeability in mining

Permeability is an important parameter describing fluid filtration processes (gas, water). In the area of USCB, the inflow intensity and chemical composition of water entering active and abandoned mines depend on the degree of the Carboniferous hydrogeological structure "opening" and lithology of the Carboniferous series in which the mine is located. Due to the conditions of supplying the Carboniferous region, the USCB area is divided into an exposed and covered hydrogeological subregion. In contrast, a different lithological formation differentiates hydrogeological properties in particular lithostratigraphic series. In the productive carbon, four lithostratigraphic series were separated, differing essentially in permeability and the ability to store and release free water. Starting from the oldest, these are: the parallel series (PS), the Upper Silesian Sandstone Series (USSS), the mudstone series (MS) and the Cracow Sandstone Series (CSS). For individual lithostratigraphic series, the permeability, in field studies, expressed by the filtration coefficient shows a high variability (Różkowski, ed. 2004) for:

- CSS from 5.0 · 10-9 m/s to 3.3 · 10-4 m/s,
- MS from 9.6 · 10-10 m/s to 5.0 · 10-4 m/s,
- USSS from 4.0 · 10-11 m/s to 2.5 · 10-5 m/s,
- PS from 8.5 · 10-9 m/s to 8.4 · 10-6 m/s.

In the north-eastern part of the USCB, permeability studies give the opportunity to assess the inflows, flows and filtration of water (the course of the study should reflect the flow directions perpendicular to the core axis, i.e. parallel to the rock stratification). For gas, these studies are of less importance. The permeability of rocks examined in the direction perpendicular to the stratification becomes more important in the case of assessing the vulnerability of groundwater to contaminants (Bukowski, Bromek, Augustyniak 2006). It can also be a relevant element in the assessment of the common hazard associated with the accumulation and pushing of mine gases from mining excavations of abandoned mines, as a result of flooding. This part of the basin is located in the hydrogeologically exposed subregion, where the Carboniferous rock mass is not effectively isolated, and thus it is easily recharged into the infiltration water from the surface and shallow deposits of aquifers that build the deposit overburden. The flooding of Carboniferous forms is mainly related to the occurrence of the complex of the Cracow and Upper Silesian Sandstone Series, in which permeable compositions predominate (Figure 1).

However, in the south-western part of the USCB, the main problem in mines is not so much related to the flow and filtration of water as to the migration of mine gases, mainly methane. It is recommended here to perform permeability tests in each direction in relation to the stratification of rocks, i.e. parallel and perpendicular to the axis of the drill cores. The filtration coefficient determined for water in this region is more important only locally for safety and boundary pillars from water reservoirs in mining excavations. In this part of the basin there is a hydrogeologically covered subregion, which is characterized by the presence of deep impermeable formation isolating Carboniferous deposits. Mines located in this part of the USCB conduct coal exploitation mostly within the mudstone and parallel series, in which there are less

favourable conditions for recharging the rock mass with water, and the coal seams are characterized by high methane capacity.

Below are exemplary tests using the PDPK-400 permeameter made on the core of the Carboniferous rock from the USCB. The tests included 33 m of the rock core with a diameter of 8.0 cm that was profiled. The studied core fragment included works of the Upper Silesian Sandstone Series from the depth interval of 355.00 ÷ 388.00 m. The measurements were carried out in the XY plane with a stage of approximately 5 cm. An exemplary graph of permeability variability of these formations as a function of depth is presented in Fig. 2.

Conclusions

The PDPK-400 permeameter allows quick identification of high and low permeability ranges of the rock layers. It allows to obtain an accurate profile of changes in rock mass permeability with a depth and to a relatively accurate separation of zones or layers with features characteristic for privileged water flow paths, migration of gases and contaminants and insulating zones, etc. The tests in the parallel lining to lamination indicate the conditions of filtration of the fluid in the layer, and in the perpendicular direction show the possibility of its percolation. Therefore, the PDPK 400 device gives complete data on the basis of which the conditions of filtration and percolation of water in any tasks of mining hydrogeology and general hydrogeology can be determined. The obtained results can be a solid base for studying model filtration processes and in rock mass composed of compact rocks. They can also be a tool for assessing the rock mass permeability in methane prevention prior to commencing mining exploitation.

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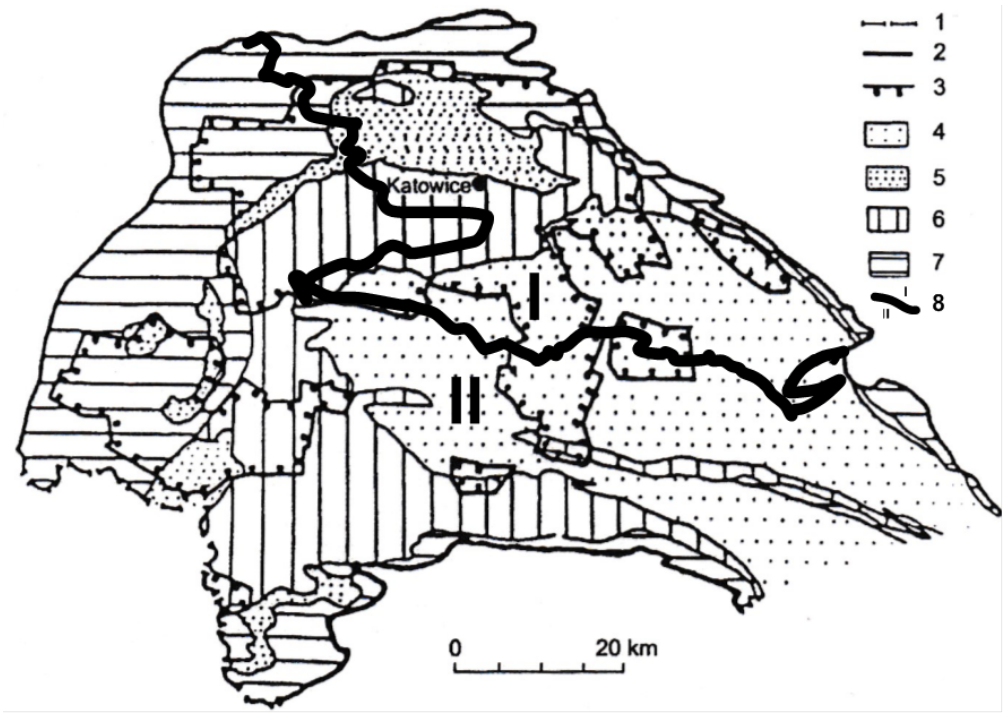

Figure 1. *A sketch of a geological map of the Carboniferous layer (according to Kotas 1982) with the range of subregions I and II (Różkowski 2003): 1 – country borders, 2 – range of USCB, 3 – mining areas, 4 – CSS, 5 – USSS, 6 – MS, 7 – PS, 8 – range of subregions*

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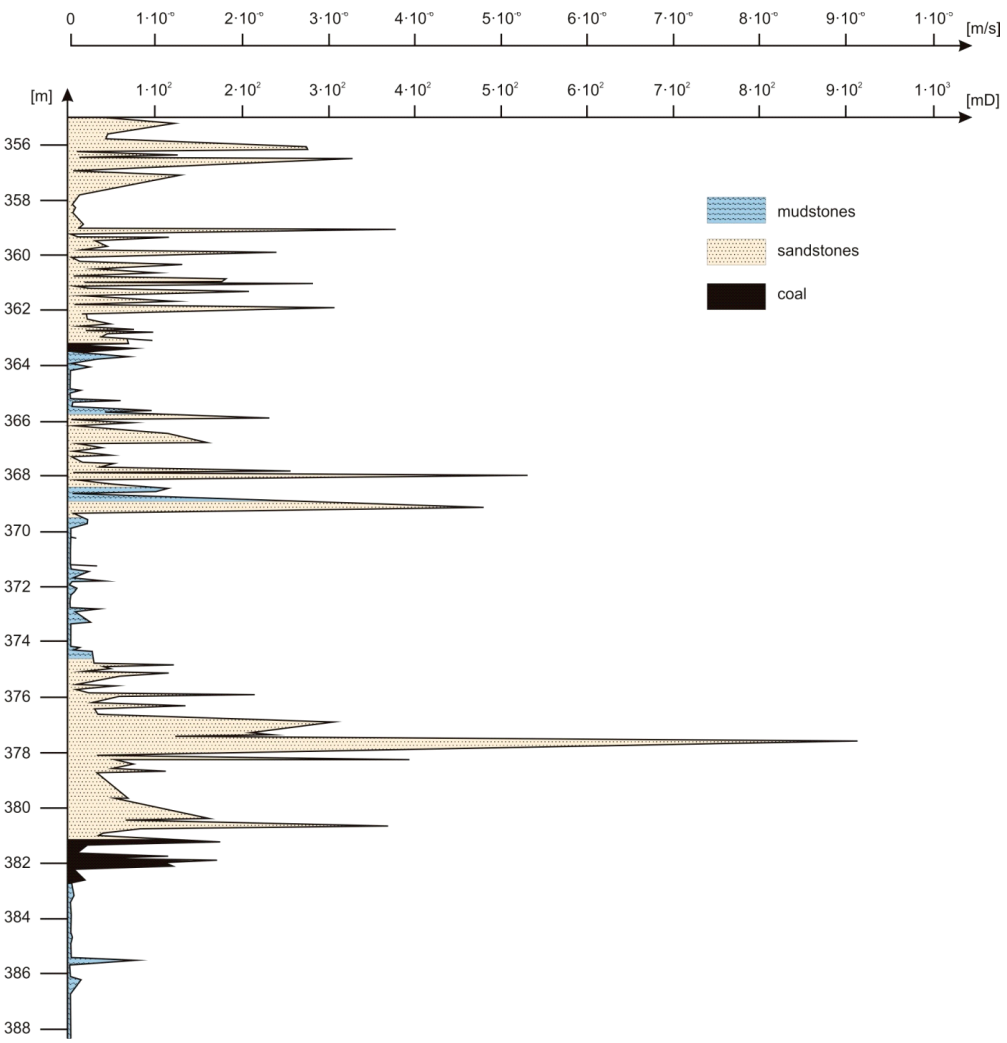

Figure 2. *Variability of permeability within the borehole profile*