Investigations in a closed mining area in China – challenges of limited datasets and understanding of hydraulic behaviour

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Abstract

A coal mine named Pangzhuang in Xuzhou, China was recently closed and the groundwater hydrogeochemical evolution process will be studied. The groundwater system has a very complicated structure, that so much work has to be done (parameter estimation, permeability measurements), before chemical analysis for the transport modelling. There are four main aquifers, named Q, 7S, C, O, in the area. Because of the partly lack of data the numerical model has to be simplified.

To solve this problem, onsite sampling work and laboratory tests were conducted. Core samples from a nearby coal mine were transported to Germany for laboratory tests. Multi-Chamber Testing Method (Mohammed 2015) was used to measure both permeability and porosity of the cores.

From the results of the above work, comparisons among different datasets are addressed including investigations reports from other coal mines in this large mining region. It can be concluded that there are huge differences between the permeability values from lab tests and the literature values. Some may differ to several orders of magnitudes. The lab tests results show a significant feature which indicate some aquifer cores are not homogeneous, but heterogeneous media. While the values from literatures are obtained by pumping tests and field drillings, the differences indicated that, groundwater in even limestone aquifers in this area is somewhere driven by fissure flow. The values of porosity also prove this conclusion in some of the samples.

Research work in this paper may indicate that groundwater flow in those target aquifers are multiply controlled by different mechanics not only by porous and karst structures but also by fissures. It is helpful for the further investigation work in this area and more accurate scenarios for further-on transport modelling.

Key words: Data shortage, hydraulic conductivity, Multi-Chamber Testing Method, fissure driven flow

Introduction

In the recent few decades, coal mines in China are having closure problems (Liu 2011). Pangzhuang coal mine which locates in Xuzhou, Jiangsu, was one of the closed mine in this large coal producing area. The whole mine was closed in 2013 with some shafts (Dongcheng Shaft) shut down in 2010. However, there are four active mines around and the closure may have impacts on the regional groundwater system. Therefore, a subject about mine closure groundwater evolution is settled. The groundwater system has a very complicated structure with four main aquifer groups named Q, 7S, C(L_4 and L_{12}), O(O_2) included. Much of basic work such as parameter estimations should be finished before transport modelling. Unluckily, the subject is suffering from a partly shortage of data, for example, important hydraulic parameters-permeability is only a range of values according to local investigation reports. To solve the data shortage problem, this paper employed some methods and tests. And significant results and new clues are found to improve further modeling set up.

Laboratory test method

The saturated hydraulic conductivity of water in soil and sediments can be measured both by onsite and laboratory tests. Onsite tests may include pumping test, slug tests, DPIL, DPST and so on. For laboratory tests, this paper used a new method named Multi Chamber Testing developed by Drilling and fluid mining Institute, Technische Universität Bergakademie Freiberg (Mohammed 2015).The method is designed to determine the permeability of tight rock samples and the interpretation of data using this method allows the permeability, effective porosity and Klinkenberg effect (Klinkenberg 1941) to be quantified by means of a single measurement run. In an operating transient two chamber method test rig porosities and permeabilities of up 10-24 m^2 can be determined on cylindrical samples.

The test rig is shown schematically in Figure 1. It consists of two stainless steel pressure chambers for the test gas (Vinlet and VOutlet) and one core holder for the test samples. The maximum test pressure may afford maximum 200 bars. The volume of the pressure chambers is about 165 ml each including the line volume. The pressure sensors at the measuring chambers have a measuring range of 0-250 bars, the maximum error of the display is smaller than 0.1 %. In addition, it is desirable to perform the tightness test on fresh core samples when possible (Mohammed 2015).

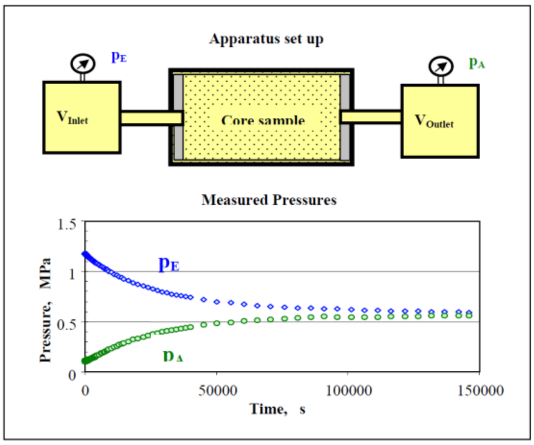

***Figure 1** Set up of Multi-Chamber Testing Method and the resulted chart (Mohammed 2015).*

Core samples preparation

As described, the data shortage is restricting the topic for gathering useful parameters. In the target closed coal mine, it is however now very difficult to operate new drilling work or boreholes to get cores since it has been abandoned. Thus, a nearby coal mine named Sanhejian was chosen as a substitute to get core samples. It is feasible because the two coal mines are both in the same regional geological unit with very similar geological structures and layers. Figure 2 shows the location of the coal mine which is only 70km away.

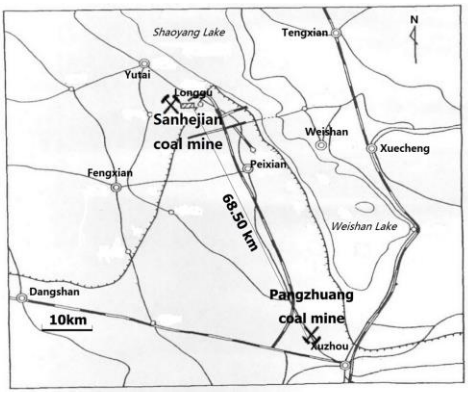

***Figure 2** Location of the substitute coal mine site for cores sampling*

In Aug, 2014, 5 core samples were collected from this coal mine with different labels representing different aquifer layers-7S, L_4, L_{12} and O_2 as well as an clay layer-7C. 7S is a sandstone aquifer while 7C is claystone. They are both the direct roof strata of coal seam 7. L_4 and L_{12} are key floor limestone aquifers of the mined layer. O_2 is supposed to be the largest and thickest limestone aquifer in the whole large region. Table 1 shows the detailed information about these layers.

Table 1 *Profiles of the core samples from Sanhejian coal mine (Regional close to Pangzhuang)*

Label number	Core rock property	Depth (m)	Formation Name	Stratum thickness(m)	Description	K(m/s) (Literature)
7C	Clay and mudstone	-300- -400	P_1s_1 (Permian)	-	Aquitard, Low permeability and the layer is the direct roof rocks for coal seam 7	-
7S	Sandstone	-300- -400	P_1s_1 (Permian)	Ave:35.64 Min:0.79	Low permeability and the layer is the direct roof rocks for coal seam 7	3.472e-8~7.963e-6
L_4	Limestone	-370- -470	C_3t (Carboni-ferous)	5.65-15.88 Ave:10.7	The thickest and most karst fracture developed limestone aquifer in Taiyuan Formation, floor aquifer of coal seam 7 and 9	3.172e-5~2.13e-4 ave:1.445e-4
L_{12}	Limestone	-450- -600	C_3t (Carboni-ferous)	2.69-9.98 Ave:6.07	Karst fracure developed, thin but is the direct roof and floor aquifer for coal seam 20 and 21	4.514e-7~9.166e-5 ave:4.605e-5
O_2	Limestone	-500- -650	O_2 (Ordo-vician)	450-530 ave:484	Thickest, strongest aquifer in the region. Karst fracure very developed	5.243e-12~0.0010677

*The core samples are listed according to the order of the depth increase (from shallow to deep).

*Label name is defined due to the naming regulation of Chinese coal mining rock layers.

*Depths showed above are illustrated from the regional cross section diagram which is only a range, not so accurate as well as the thickness. Other parameters are also from regional geological investigation reports.

Results and discussions

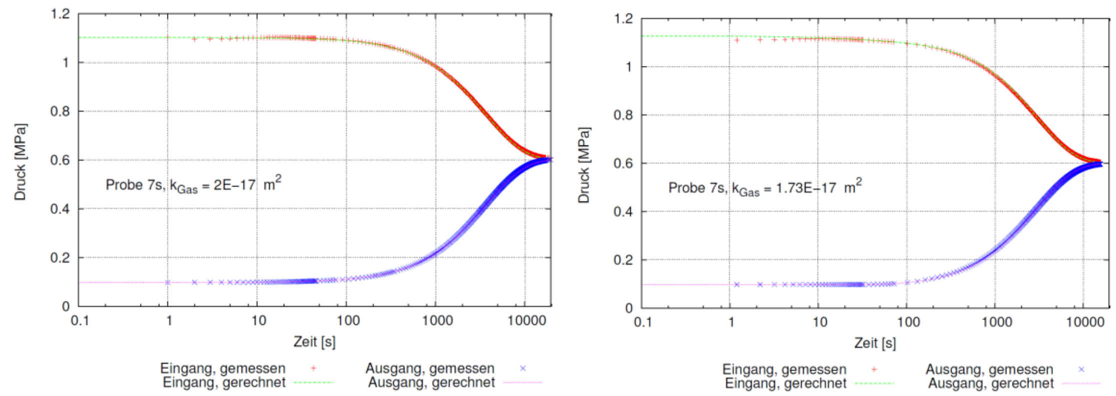

Figure 3 *Test results of core sample 7S and 7C*

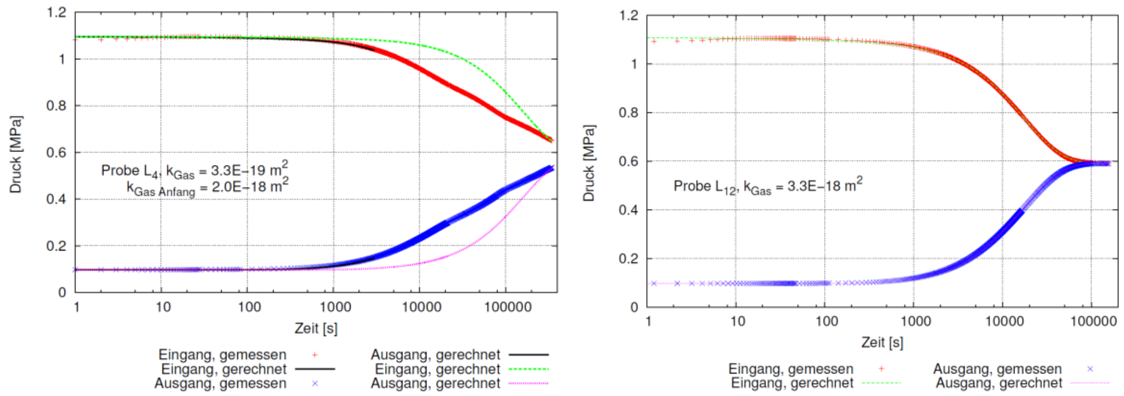

Figure 4 *Test results of core sample L_4 and L_{12}*

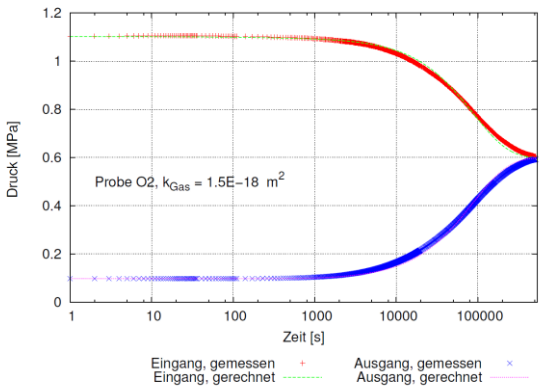

Figure 5 *Test results of core sample O_2*

Figure 3-5 show the tests results of the permeability values. Then, the equation below (Frieder, et al. 1985) was used to transfer the $k_{gas}(\kappa)$ value to K. After calculation, the results are compared with other local coal mines literatures and some geological investigation reports which are shown in Table 2.

$$\kappa = K\frac{\mu}{\rho g}$$

where

- κ is the permeability, m^2
- K is the hydraulic conductivity, m/s
- μ is the dynamic viscosity of the fluid, kg/(m·s)
- ρ is the density of the fluid, kg/m^3
- g is the acceleration due to gravity, m/s^2.

Table 2 *Permeability values Comparisons between lab tests and literatures**

Core label	Lab Measured results(m/s)	Literatures Pangzhuang(m/s)	Literatures Zhangshuanglou(m/s)	Literatures Wanbei(m/s)
7S	1.73E-10	3.47E-8~7.96E-6	1.62E-8	7.64E-8~1.68E-5
7C	2E-10	-		
L4	3.3E-12	3.17E-5~2.13E-4 ave:1.45e-4	6.92E-5~1.51E-4	1.88E-4
L12	3.3E-11	4.51E-7~9.17E-5 ave:4.61E-5	8.66E-6~1.33E-4	5.47E-5
O2	1,5E-11	5.24E-12~1.07E-3	3.72E-6~5.6E-5	2.73E-5~6.97E-4

*Literature values collected from several different related reports listed in references

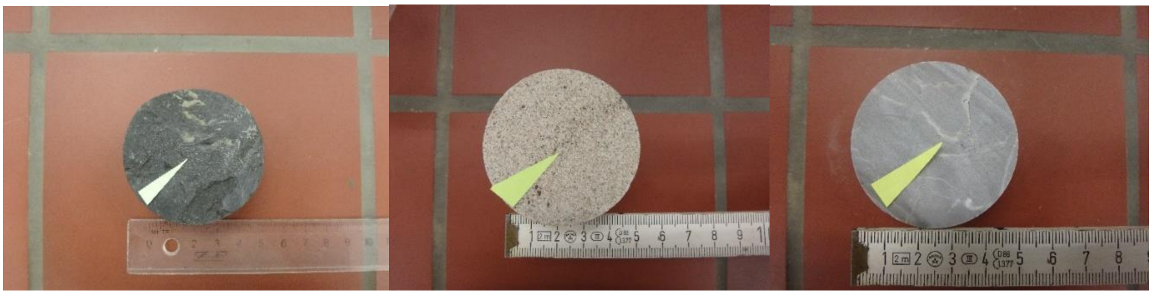

Figure 6 *Cross section surface of core sample 7C(left), 7S(middle) and L_4 (right)*

Figure 7 *Cross section surface of core sample L_{12}(left) and O_2(right)*

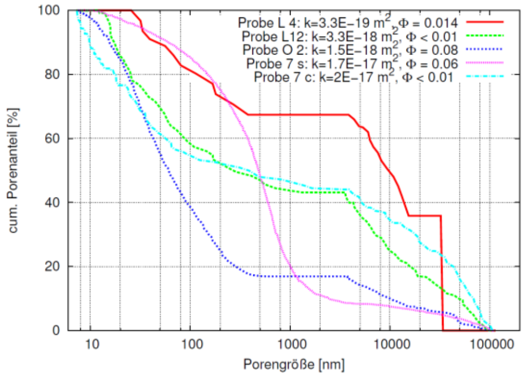

Figure 8 *Porosity test results of each core*

The table 2 shows clearly that there are huge differences of the lab obtained permeability values compared with those from literatures and reports. Some of the samples may differ from several magnitudes, for example, L_4 and L_{12}, literature values are 10^5 or even 10^8 times larger. Only 7S and O_2 have relatively similar values but still too small as aquifers.

Additionally, those cross section surface pictures also indicate, most of the matrixes collected from the nearby coal mine are to some extent heterogeneous with very compact properties. This could be verified from the Figure 8 which demonstrates all of the cores' porosity measured values. These values range from 0.01 to 0.08 are all not typical or representable for aquifers because normally a permeable aquifer should have a much higher value.

Therefore, the possible reasons why there are such differences between lab tests and literatures may lie on several different points:

1) The mine site is not exactly the right coal mine those literatures described although they are all in the similar region, the characteristics of the hydrogeology may vary locally.
2) Lab test method is generally used for matrix measurements while those literatures values were obtained mostly from a site pumping or slug tests. They have different scales and represent various aspects of the strata properties.
3) Another reason that could be spoken is that the groundwater hydraulic behavior in those layers are also driven by fissure flow or fractures flow not only porous and karst flows. This could be a conclusion for this paper and the proof may also be seen from both tests results and pictures

of the cross section surfaces. Most of the cores are not homogeneous but heterogeneous. The large ranges of K values from the literatures may also indicate this.

4) Those core labels may not be so accurate since these cores samples were not collected from the very drilling scene or sites. Thus they may be not so reliable to measure with.

Conclusions

To overcome the data shortage difficulty, this paper adopted several different methods, some of them are developed by TU Freiberg. This Multi Chamber Testing is a reliable and accurate method to measure the permeability values of the cores which is feasible to avoid some technical errors and influencing effects. However, the measured values of the tests showed a large difference with those written in related reports and literatures, some may differ to certain magnitudes. Together with the analysis of the core samples cross section surface pictures, the matrixes appearances seem to be more heterogeneous instead of homogeneous. All of the comparisons, values of permeability themselves and matrixes surfaces pictures lead to one conclusion: the hydraulic behavior may be not only driven by karst or porous power, but also to some extent by fractures and fissures which is contained in those aquifer rocks. On the other hand, the huge differences between literature and lab tests may result from several potential reasons: distance from the target coal mine, the incorrect labels written in the cores and so on.

To summarize, this paper has investigated the closed coal mining area with some of the lab tests and analysis to solve the data shortage problem encountered in the topic and the conclusion is showing a special properties of the aquifers in this region. The aquifers are to some extent a heterogeneous structure and the hydraulic behavior inside may not only be driven by normal porous or karst media but also by lots of fissures and fractures. This information is of great importance for further modelling process. And the investigation has also given critical comments on the rock cores sampled from the nearby mine site. It is therefore quite beneficial for future research work even to set up a more reliable and more representative groundwater flow model.

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