Dewatering of Multi-aquifer Unconsolidated Rock Opencast Mines – Alternative Solutions with Horizontal Wells

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Abstract The objective was to develop an innovative dewatering technique based on Horizontal-Directional-Drilling (HDD) that reduces environmental impact on excavations and open pit mining. Laboratory, pilot and field experiments produced results that could be used to better understand the important processes and reproduce them through modeling. A new algorithm based on the flow equation by Gauckler-Mannning-Strickler was developed and introduced into the groundwater modeling system PCGEOFIM®. This allows calculating open channel flow in the model. Experimental and numerical results clearly showed the advantages of HDD-wells over vertical wells such as better dewatering effects in thin aquifers and interruption-free mining operations.

Key Words dewatering, Horizontal-Directional-Drilling (HDD), modeling of groundwater flow with horizontal wells, PCGEOFIM®, dewatering experiments

Introduction

Dewatering of the subsurface is the prerequisite for many mining activities. Vertical wells are the state of the art for dewatering but have short screen sections in thin aquifers. In addition, the active screen section is continuously reduced due to the dewatering progress. Therefore, a large number of vertical wells need to be installed and operated to achieve the desired dewatering effect. Every single well needs to be equipped with a low capacity pump connected to a power supply, electrical equipment, penstock as well as control and feedback control systems.

The horizontal well technology is based on Horizontal Directional Drilling (HDD; Kleiser 1996; Fengler 1998; see fig. 1a) and offers the possibility to partially dewater the aquifers by using the free gradient along the wells. The water flows freely into an open pit and can be pumped from there with a efficient large pump. Due to the long screen section of horizontal wells the pumping

Figure 1 *(a left) Installing an HDD-well (Drill rig). (b right) The laboratory test station in bird view*

rate can be significantly higher than for vertical wells. The number of wells is much smaller for achieving the same dewatering effect. This results in a decrease of pumping energy and material. On the other hand, the HDD technology is still a subject of ongoing investigations.

Methods

Laboratory tests

Laboratory experiments measuring the effects of horizontal well dewatering were carried out. The test station shown in fig. 1b has a base area of 6 m·6 m and a height of 2.5 m. It was partially filled with aquifer material with a volume of approximately 70 m³. Three sides of the test station are equipped with cells to define constant head boundary conditions by keeping a specified water level. A horizontal filter screen dewaters the container through the forth side. The outflow rate and the flow towards the boundary condition cells were measured with two electromagnetic flow meters.

Experiments were set up varying the type of filter screen and filter screen diameter, the annulus space fillings, the inclination of the filter well, the water level of the boundary condition cells, and effective filter length in different combinations.

Field tests

The field experiments focused on practical drilling problems and the portability of laboratory experiments to the field scale. Therefore, a horizontal well was installed using HDD technology in the MIBRAG-managed German lignite mine "Vereinigtes Schleenhain" located 30 km south of the city of Leipzig. A monitoring system was installed comprising 21 observation wells. An electromagnetic flow meter measured the well outflow. The HDD-well was placed in a sandy, semi-confined aquifer. The filter section had a length of 60 m moving along a small dell in the deepest part of the mine and draining the water from a part of the aquifer with a thickness of 3 to 6 m. PVC wire-wound screen was used for the HDD-well. To the knowledge of the authors this was first time this material, which is normally used for vertical wells was applied to HDD-wells. Mining machinery can easily cut the material allowing continuous mining operations while maintaining dewatering. The freely out-flowing water was collected in a vertical shaft and from there pumped allowing accurate flow measurements (fig. 2a). The experiment was run continuously without interruptions. This allowed operating the well in steady-state as well as monitoring the recovery of the water table after the outflow was stopped. The extensive investigations of the subsurface properties included laboratory experiment such as determination of conductivity from grain size distribution, field tests such as slug and bail tests as well as small-scale stratigraphic investigations and tracer test.

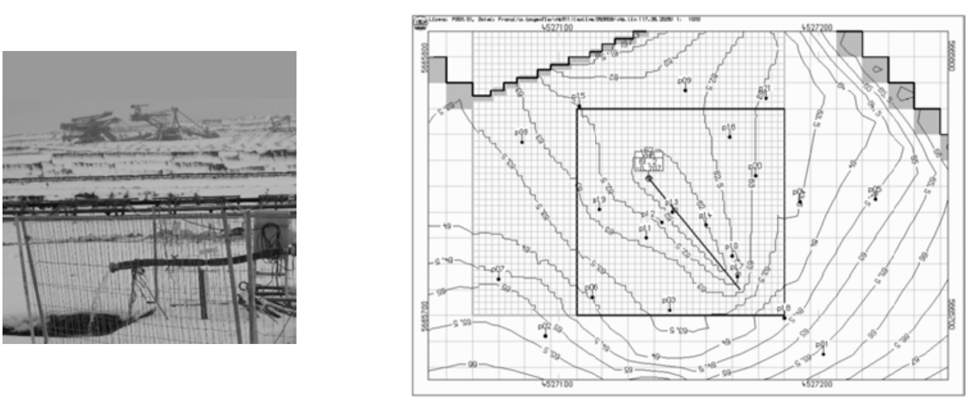

Figure 2 *(a left) Field test station at lignite mine "Vereinigtes Schleenhain". (b right) Field Steady state hydro isohypse plan for the field test*

Numerical modeling

Both laboratory and field experiments were designed based on numerical modelling of flow in porous media using the finite volume groundwater flow and transport model PCGEOFIM®. PCGEOFIM® is a sophisticated model specifically designed for modeling groundwater flow in open pit mining areas.

The model for the laboratory experiments was discretized with 10 by 10 by 10 cm finite volume cells allowing a very detailed representation of the flow conditions. Parameterization of hydraulic conductivities and porosity was based on grain size distribution measurements and slug and bail test in the laboratory setup. The model results were used to determine measuring ranges of flow meters and volumes of buffer storages for water circulation. Based on the experimental results, the model was constantly improved to better represent the measured values.

The model for the field experiments was setup as a 3D-model with several nested telescopic mesh refinements to allow detailed representation of the near-well regions and at the same time to cover a large enough area while keeping the model runtimes manageable. The model discretization is shown in fig. 2b along with the calculated water table for steady-state conditions. Model parameterization was based on hydrogeological data collected with drillings, grain size distributions and slug and bail tests.

The model was used to plan the location of the observation wells as well as to estimate the outflow of the well to dimension the flow meter. The model was calibrated against observed heads and well outflow.

Results

PCGEOFIM® originally used an embedded analytic solution for calculation of withdrawal with horizontal wells, which is based on the modified solution for vertical wells (Busch et al. 1993). Comparing measured and calculated values for heads and well flow rates showed significant deviations that could not be reduced through reasonable parameter adjustments. Even though groundwater heads were well above the well, channel flow could be observed in the well. Therefore, the algorithm for calculating well outflow was improved to actually represent the flow in the well itself. Both channel flow and pressure flow in the well were implemented in the numerical solution. Schematics for both methods as used in the model are shown in fig. 3.

The inflows into the well are calculated as a function of head difference between well- and groundwater-levels, the colmation in the vicinity of the well, and the well geometry. Every well cell receives groundwater inflow that will flow to the neighbouring downstream cell.

The channel flow is based on the Gauckller-Manning-Strickler approach with a modification to avoid unstable flows at high well water levels. This allows representing the flow within the well with a numerically stable solution. The principle is depicted in fig 3 (left) and shows the inflow from groundwater to each cell as well as the flow to the adjacent downstream cell.

Pressure flow occurs when the well water level reaches the upper well boundary. Now the hydraulic head rather then the slope will be used as the driving force. Pressure flow is modeled using a pipe hydraulics approach. The loss of hydraulic head due to friction and other process is represented in the model as can be seen in fig. 3 (right).

Using the improved model good correspondence between measured and calculated outflow rates good obtained as shown in fig. 4. The improved model was used to compare the dewatering effects of the installed HDD-well in the field experiment with the effect of vertical wells. Seven vertical wells would have been necessary to achieve the same dewatering effect. Therefore, the

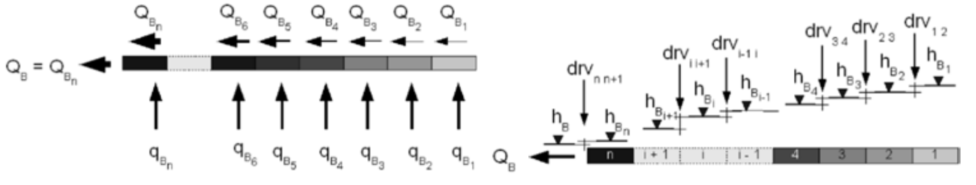

Figure 3 *Schematics of channel flow (left) and pressure flow (right) in the horizontal well screen as used in PCGEOFIM®*

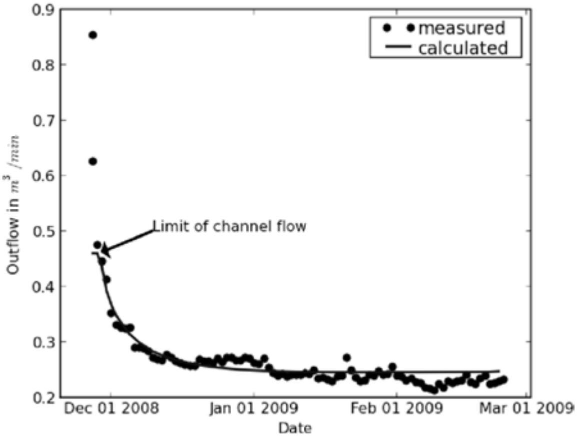

Figure 4 *Measured and calculated outflow rates over time for the field experiments*

use of HDD-well yields significant savings in energy and material consumption. Furthermore, there is no need to remove the HDD-well. This allows continuous operation as opposed to vertical wells that need to be removed some time before excavation allowing re-rise of heads. The model results showed that water levels would be nearly back to original levels after two weeks without dewatering. As this is the time required by technology to remove vertical wells before excavation, there would effectively be no effect for dewatering.

Conclusions

The laboratory and field measurements yielded new insight in processes at vertical wells with free outflow. The iterations between modeling and modeling with mutual incremental improvements proved valuable. The detailed measured data provided a basis to improve the algorithms for calculating of horizontal wells within PCGEOFIM®. The resulting model can be used to predict outflow rates of horizontal wells with free outflow with a higher accuracy helping to improve planning of dewatering. Advantages of HDD-wells over vertical wells could be quantified.

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