Dewatering of Opencast Mines using Horizontal Wells

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Abstract

As part of many mining and civil engineering projects that are realized in mining and in open pits, rock layers must be drained first to allow the excavation, the transport of mass and the tilt. This drainage is done nowadays mainly using vertical wells. Especially in thin aquifers the extractable water quantity by a single well is limited. Since vertical wells may interfere with land use rights over the location of water catchments, the possibilities of horizontal drainage using Horizontal-Directional-Drilling (HDD) are of increasing interest. There is a high potential to achieve the drainage capacity of many vertical wells by using fewer HDD-wells. Furthermore, this allows for significant reductions in material and energy use as well as conservation of existing land use and groundwater resources. Based on the results of the first phase of the project which dealt with the oncoming flow in HDD-wells, the second phase addresses the hydraulic effects of the elements environmental impacts, profitability, and the applications on an industrial scale.

Introduction

Dewatering of near-surface unconsolidated rock material is an important prerequisite for the technical implementation and safety of mining projects. There is hardly any alternative to the necessary removal of water from the water-bearing strata in the overlying rock. Furthermore, the removal of water from the overlying rock is also a basic prerequisite for stable slopes and bermes. For this purpose, considerable volumes of water are pumped annually in the construction and mining industries, about 1 billion cubic meters in Germany's open-cast lignite mines alone. Subject to the geological/hydrological conditions of deposits, particularly in basin structures, the pressurized water level may also have to be relieved and sometimes drained below the base of an excavation. Otherwise there would be a risk of footwall failure with water escaping from the ground. Higher residual water levels in overburden operations and out-of-control rising ground water levels could cause slides. A lot of negative experience has been gained with such hazards in lignite mining.

Nowadays vertical filter wells are commonly used on a large scale to lower the groundwater table and to relieve groundwater pressure. Subject to hydro-geological conditions, the lowering of ground water tables usually cannot be limited to the immediate mine area itself, even more so as this process must take place in advance to guarantee compliance with given geotechnical and hydrological target values. This has a negative impact on the hydrological balance and must, therefore, be minimized.

The aim of the project

Based on the results of a successfully completed phase I the aim of the 2nd phase of the research project (both phases funded by the Deutsche Bundesstiftung Umwelt, DBU, [German Federal Foundation for the Environment]) is to develop - the scientific and practical bases for the application of an alternative dewatering method using vertical filter wells, i.e., curved filter wells (Horizontal Directional Drilling - HDD) and to overcome the environmental drawbacks of the use of vertical filter wells as efficiently as possible.

Currently, the curved dewatering technique in lignite mining is limited to a few individual cases, but has great potential for easing the environmental burden of mining projects (Müller et al. 2009).

Method of curved horizontal directional drilling

Figure 1shows how curved horizontal directional drilling can be performed with relatively little effort beneath an area that otherwise could only be crossed underground with difficulties or not at all.

Figure 1 *Schematic presentation of horizontal drilling (Tracto-Technik 2010)*

As a rule, the work is divided into three successive steps – pilot bore, reaming(s) and pulling in pipes or filters.

A complete dewatering of the overlying rock, e. g., of an open-cast mine, or of the relieved aquifer of a footwall opens up a complete new range of applications for the curved filter well technique. Basic principle is to let the water that runs off the HDD filter wells pour off freely at the lowest point of the well.

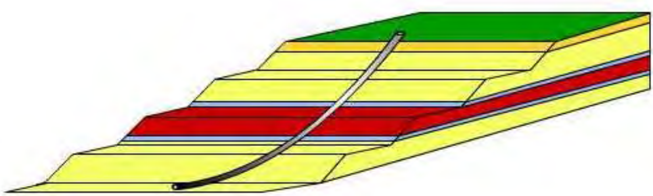

Figure 2 *Horizontal filter wells in working direction across a geological structure*

Figure 2 shows in working direction across a deposit, how the HDD well installed in the mountains could work while the water can flow out on the individual levels time and again when the well is mined through from lower to higher cuts.

That means, there is no need for pumps or installations of wells and not even for energy to pump the water from the individual wells. Consequently, no pipelines are required to receive the water from the individual wells and to pipe it to a central water station as is the case with vertical wells

The prospective field of an open cast mine is stressed only prior to the actual surface excavation when the HDD wells are installed. The number of required wells may be much lower due to the several times longer wetted filter screen compared to vertical wells.

The freely outflowing water must be drained into collection trenches and water stations and be pumped by large pumps whose efficiency is much higher than that of the many small pumps that ought to be installed in the vertical wells. As a consequence power consumption will decrease. Such wells may be used in both, active slope systems and final and periphery slope systems.

Depending on geological and hydrological conditions and the geological structures, various modifications and designs respectively are possible due the flexible installation of HDD filter wells. Based on preliminary studies, several options are conceivable.

Option 1: As illustrated in figure 3, a drill hole with an exit opening can be equipped with a submersible pump if the dewatering takes place close to the surface.

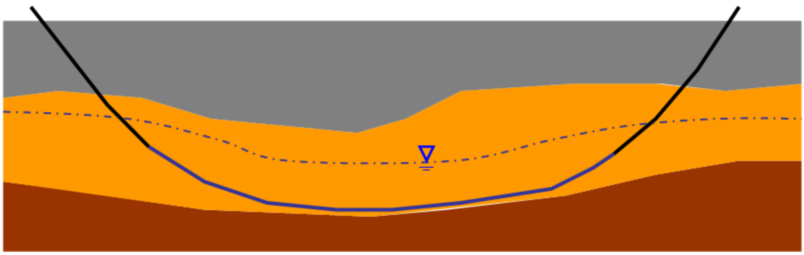

Figure 3 *HDD well with submersible pump close to the surface with exit opening (Struzina, M (2012)*

Alternatively, a close-to-surface filter train can also be connected to a collection shaft (Figure 4) allowing natural flow from the filter train as needed.

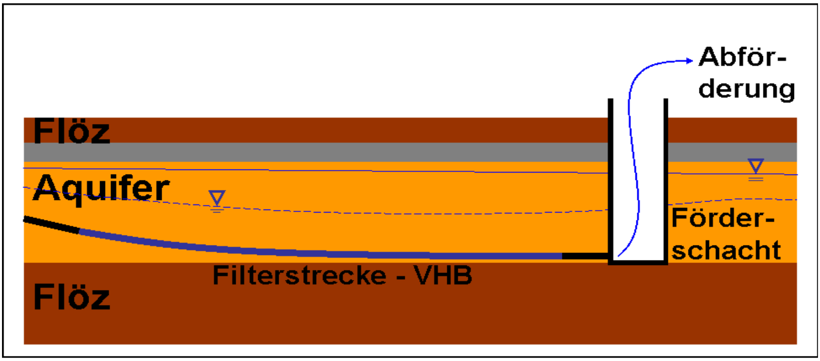

Figure 4 *Close-to-surface HDD filter well with collection shaft* ***(****Struzina, M (2012)*

Option 2: In a mine‘s border slope system, HDD wells are drilled along the slopes. The water flows through their entry opening into water collection trenches put in place at the bottom of the slope from where the water is drained. Such a solution is illustrated in figure 5 whereas in certain cases several slopes can share one well.

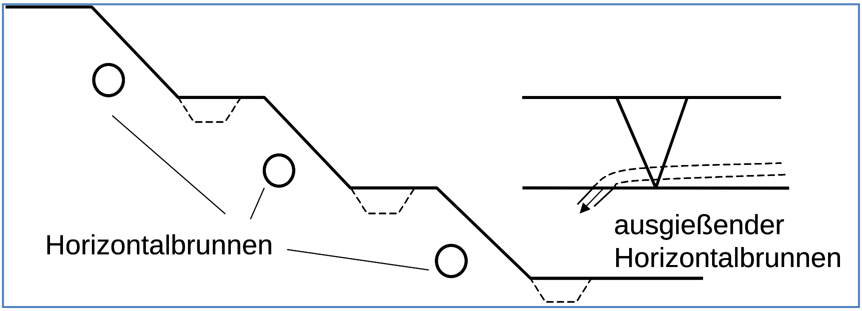

Figure 5 *HDD filter well in a mine's border slope system (Horizontalbrunnen = horizontal well; ausgießender ~: decanting horizontal well)*

Option 3: The only alternative to vertical filter wells for dewatering projects with multiple aquifers are either HDD wells to be drilled in each aquifer or the connection of vertical injection wells with curved horizontal wells (HDDB).

In addition to HDDB drilling which is comparably expensive, this option offers a cost-efficient alternative for continuous concentrated drainage of all horizons using one HDD well for all aquifers. For this purpose, all vertical injection wells are directly or indirectly connected with the horizontal filter train in the deepest aquifer to be drained. The water of low lying and hanging aquifers drained by injection wells flows to the bottom or deep-lying aquifer and is pumped through the HDD well put in place there (Figure 6).

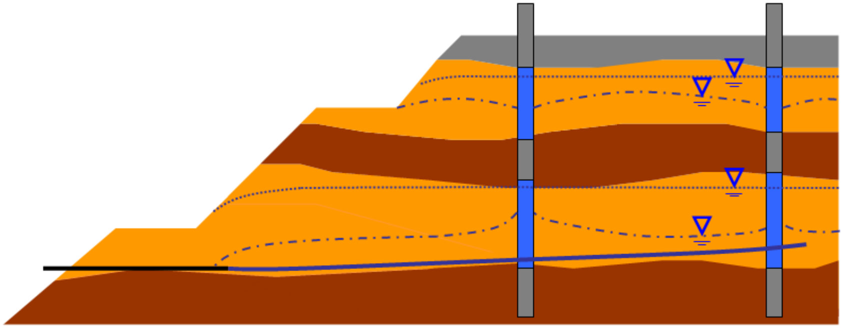

Figure 6 *HDD well in connection with vertical injection well (Struzina 2012)*

Further options and opportunities for the modification of HDD wells shall be examined and developed subject to the geological conditions and technological boundary conditions of construction sites and mining operations in order to guarantee optimal drainage.

Development of improved calculation methods and modeling

For planning and consulting engineering activities, the Ingenieurbüro für Grundwasser GmbH (IBGW) uses the PCGEOFIM® program (Sames et al. 2011) developed in house. This program was developed primarily for active mining and reclamation mining and is used for these purposes by other institutions as well, among others by the Mitteldeutsche Braunkohlengesellschaft mbH (MIBRAG), Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH (LMBV), TU Bergakademie Freiberg, Vattenfall Europe Mining AG, Dresdner Grundwasserforschungszentrum e.V. (DGFZ) and more.

Based on the results from bench-scale and field tests and their model-aided monitoring in project phase 1, new knowledge was gained concerning the open channel pipe flow in the horizontal well as well as the pressure pipe flow by involving the pressure losses.

Figure 7 shows the impact of an HDD filter well on the groundwater flow when the well is fully flown and a pressure flow occurs in the filter pipe (left) and when the well is subject to a non-full flow and open channel flow in the filter pipe (right). Only the case of a full flow with pressure flow in the filter pipe has so far been correctly modeled and tested. Further possible are the case of full flow and open channel flow (this case was observed in a field test during project phase 1), the case of non-full flow and pressure flow and the case of no flow.

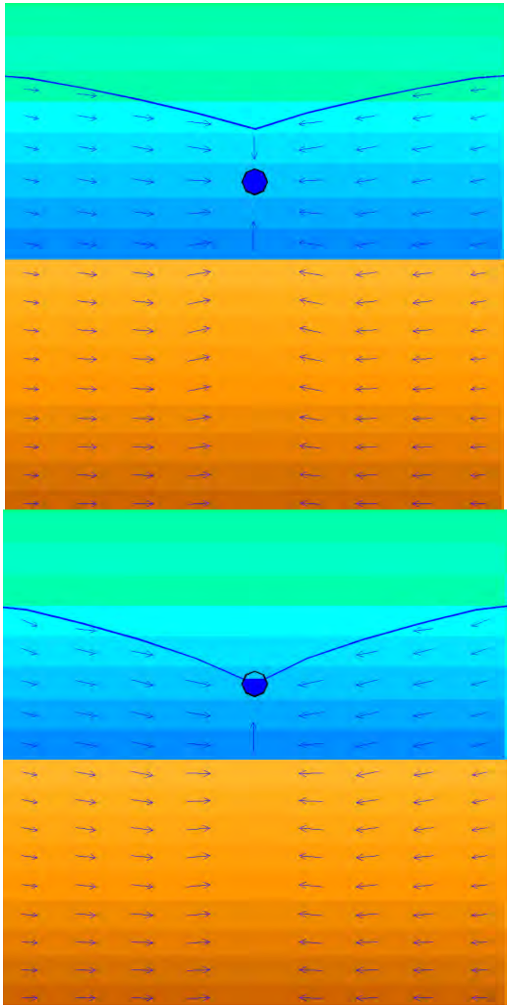

Figure 7 *Full (left) and non-full flow (right) to a horizontal well with pressure pipe and open channel flow*

On the basis of the results and knowledge gained from the tests performed in project phase 1, open channel pipe flow was realized in the groundwater model of the PCGEOFIM software system and theoretical findings were made with regard to pressure loss behavior in pressure pipe flow scenarios.

For a comprehensive algorithmic presentation of the possible impact of HDD filter wells on the groundwater table, it will be necessary to develop further algorithms clearly describing the connection between the water level in the filter pipe and the water volumes flowing – in sections - into and out of the horizontal well. However, a solution has not yet been found for a case where both flows, i.e. open channel and pressure pipe flow, occur in the HDD filter well. The tipping point between open channel and pressure pipe flow shall be subject to further investigations in bench scale testing.

The capacity of an HDD filter well is limited by the pressurized water flow. Only a limited amount of water can be transported per time unit subject to length, diameter, pipe roughness and gradient. The formulas for pressure and open channel pipe flows are known. However, in phase 1 of this research project, new knowledge has been gained after considering open channel pipe flow in the model and findings were made with regard to the calculation of occurring pressure losses. The use of HDD filter wells as open channels with a free water surface following the conventional approach of Manning/ Strickler (pipe channel) enabled a more accurate representation in the model. Inflows to the individual HDD well sections are shown in figure 8.

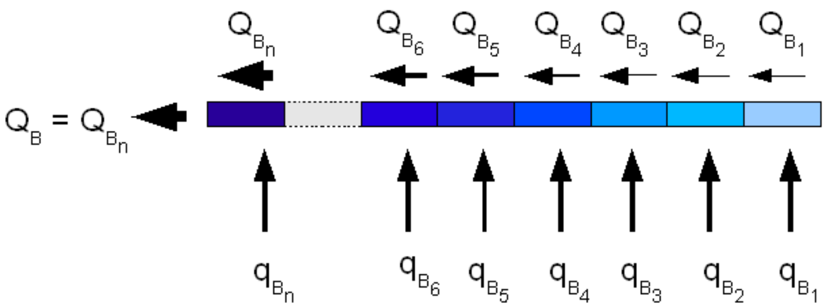

Figure 8 *Calculation of the through flow in an HDD well used as an open channel*

Figure 9 shows a graph of water levels and pressure losses. Calculations follow the iterative method using an initial guess.

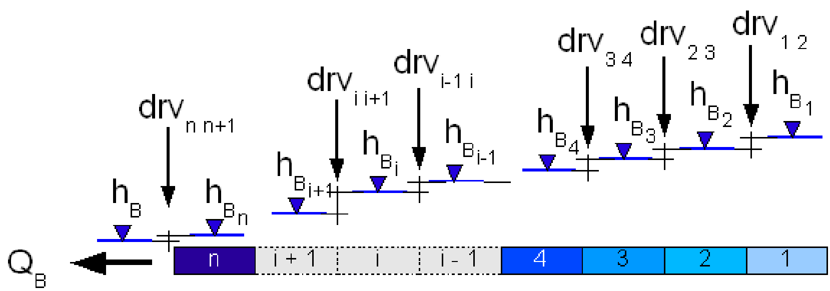

Figure 9 *Calculation of pressure losses in a pressure pipe flow scenario*

The theoretical knowledge gained in phase 1 with regard to the calculation of pressure, open channel pipe flows and pressure losses shall be implemented, verified and tested in the model algorithm within the scope of further research to be conducted in project phase 2.

Project work plan

Further work on the project will be focused on two parallel key subjects based on the results gained in the first project phase.

The first subject will include bench scale testing in order to evaluate the data for modeling. The focus will be on the extension of the data basis on one hand and on further investigation needs identified as necessary from the results of the first project phase on the other hand.

The second subject will be dedicated to a field test with a practical application of curved dewatering drilling in a multiple aquifer scenario.

Additionally, the investigations shall also include the exploration of opportunities for drainage modeling using curved horizontal drilling as a two-phase model.

Bench scale and field tests will be prepared on the basis of the model and exemplarily supported by the PCGEOFIM software system. Furthermore, model calculations will be run on the two-phase flow. Mathematical formulations changed as a result of phase I will be analyzed, further developed, supplemented in the PCGEOFIM software system within the scope of the evaluation of bench scale and field testing and will be compared with the results of the Mod2Phase calculations.

The planned field tests shall demonstrate that the knowledge gained in the lab and in bench scale testing can be verified in practice.

Acknowledgements

Thanks go to DBU (Deutsche Bundesstiftung Umwelt) Herr Heidenreich, Dr. Dietrich Sames, Dr. Michael Struzina and MIBRAG for their contributions to this document and supporting this work.

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