Dewatering of Opencast Mines Using Model-Based Planned Horizontal Wells

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ABSTRACT

As part of many mining and civil engineering projects that involve surface excavation, rock layers must be drained first to allow excavation, removal, and disposal of rock and soil. Today this drainage is mainly achieved by using vertical wells. Especially in thin aquifers the extractable water quantity by a single well is limited due to a very small length of the screen section. Since vertical wells may interfere with land use rights over the location of water catchments, horizontal drainage using Horizontal-Directional-Dewatering (HDD) is 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 reduction in material and energy use, 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, cost effectiveness, and application on an industrial scale.

Keywords: PCGEOFIM, Groundwater modeling, horizontal wells, Horizontal-Directional-Dewatering (HDD)

INTRODUCTION

Dewatering of near-surface unconsolidated rock material is an important prerequisite for the technical implementation and safety of mining projects. The removal of water from the overlying rock is also a basic necessity for stable slopes and benches. 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. Regarding the geological/hydrological conditions of deposits, particularly in basin structures, the piezometric pressure may also have to be reduced, 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 through 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. Depending on hydro-geological conditions, the lowering of ground water tables cannot usually be limited to the immediate mine area itself, even more so as this process must take place in advance to guarantee compliance with geotechnical and hydrological target values. This has a negative impact on the regional hydrological balance and must, therefore, be minimized.

METHODOLOGY

Based on the results of a successfully completed phase 1 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 basis for the application of an alternative dewatering method , 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). Figure 1 shows how curved horizontal directional drilling can be performed with relatively little effort beneath an area that otherwise could only be accessed underground (with difficulty) or not at all.

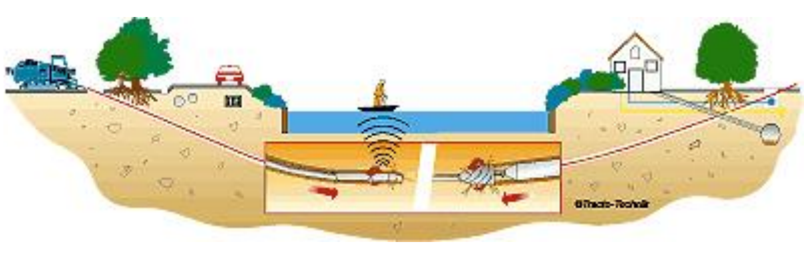

Figure 1 Schematic presentation of horizontal drilling (Tracto-Technik 2010)

As a rule, installation of HDDS 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.

The basic principle is to let the water that is produced by the HDD filter wells discharge freely at the lowest point of the well.

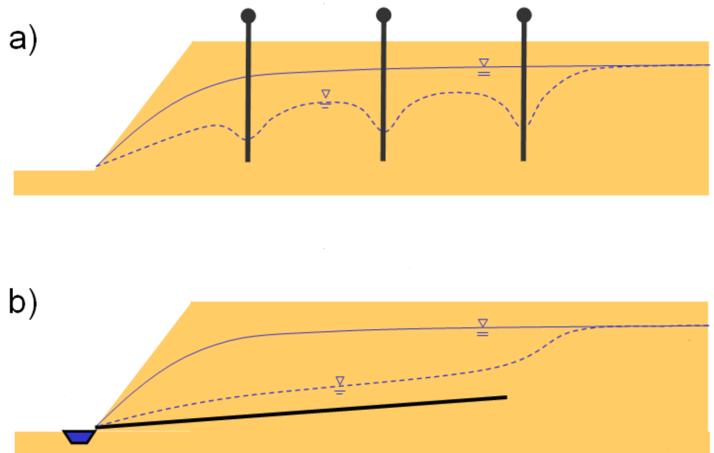

Figure 2 Drainage of overburden material at slopes of open-cast mines, a) using conventional vertical wells, b) using horizontal filter wells (Eichler 2013)

Figure 2b shows how the HDD well is installed in the rock formation next to the slope. Thus the water flows out by gravity continuously. Due to the mining progress material of the slopes is excavated and the end of the well will be cut time and time again. However, the water produced by the HDD flows out at the in-pit end of the well. The water will be collected by a trench on the bench and led to a central pumping station at the deepest point of the open-cast mine. By this means, there is no need for pumps or installations at every single well. Consequently, no pipelines are required to receive the water from the individual wells and to pipe it to a central water station as it is in the case of using vertical wells. The real field of an open cast mine is directly used only prior to the actual surface excavation when the HDD wells are installed. Furthermore, while the length of the effective filter section of vertical wells is reduced due to sinking water level, the effective filter length of horizontal wells remains constant. As a result, 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 will be collected at a central water station and pumped by large pumps whose efficiency is much higher than that of 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 to 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. Alternatively, a close-to-surface filter well can also be connected to a collection shaft (figure 4) allowing gravity flow from the HDD and extraction from the collection shaft as needed.

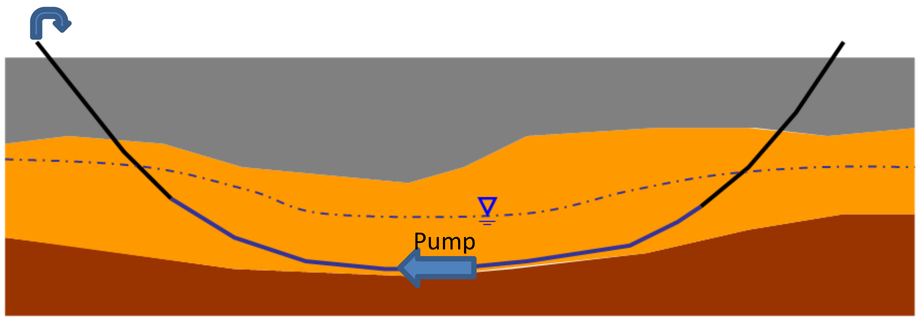

Figure 3 HDD well with submersible pump close to the surface with exit opening (Struzina 2012)

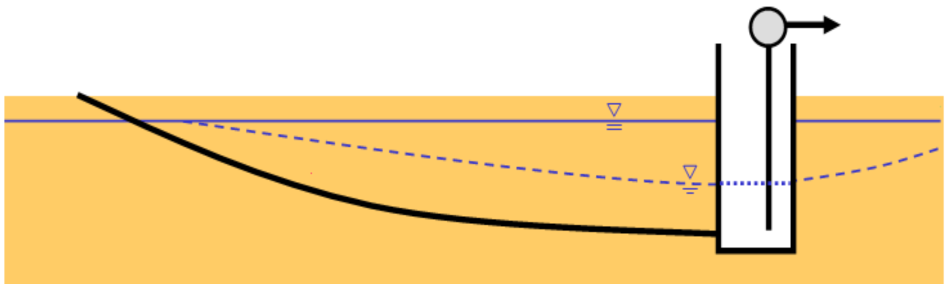

Figure 4 Close-to-surface HDD filter well with collection shaft

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 be dewatered by one HDD well.

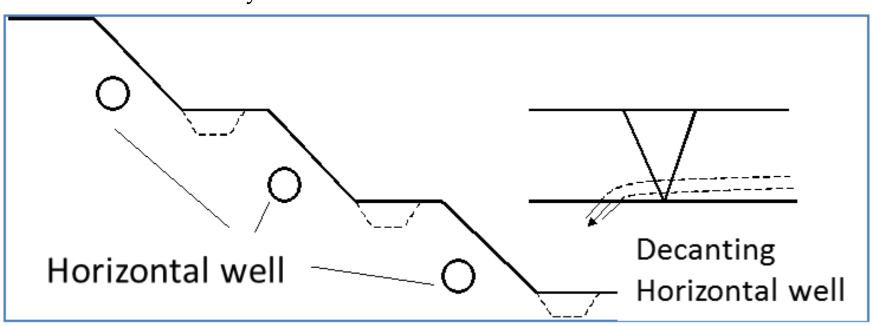

Figure 5 HDD filter well in a mine's border slope system

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 infiltration wells with curved horizontal wells .

In addition to HDD 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 wich has been put in place there (figure 6).

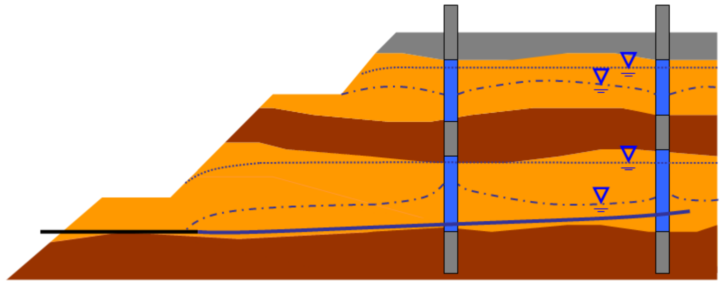

Figure 6 HDD well in connection with vertical injection well (Struzina 2012)

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

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 them are 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.

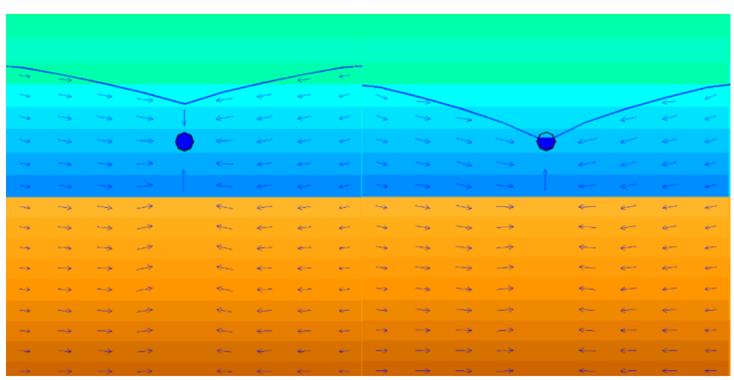

Figure 7 Full (left) and non-full flow (right) to a horizontal well with pressure pipe and open channel flow

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 been found for a case yet 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.

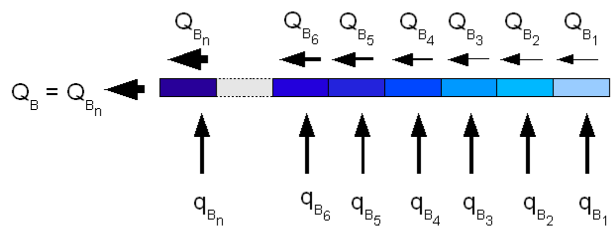

Figure 8 Calculation of the through flow in an HDD well used as an open channel

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

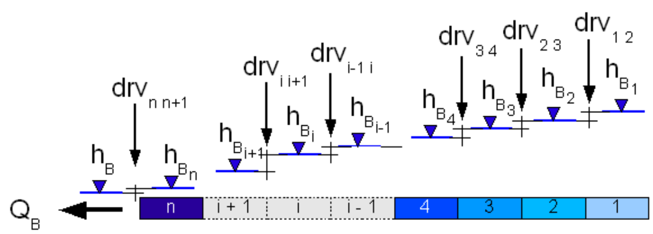

Figure 9 Calculation of pressure losses in a pressure pipe flow scenario

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.

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 if 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.

RESULTS AND DISCUSSION

Within the scope of both the bench scale testing and field test to be done in the project phase, a geological structural model was created. Based on that model, a numerical groundwater model for the simulation suite PCGEOFIM was developed. By means of available measurement values, the groundwater model was calibrated for the startup time of an HDD-well to allow for prediction simulations. During the test phase, the model statement was continuously recalibrated on base of newly available observations (figure 10). The results obtained from both, the bench scale testing and the field test, were used to improve the knowledge of processes in the close range of HDD-wells. By means of accompanying research and mathematical model development, new algorithms were implemented into the groundwater simulation suite PCGEOFIM. A significant result is the consideration of head loss in the well pipe and its effects to the surrounding groundwater flow. The section below describes modeling results of the field scale test. It emphasizes the comparison of measured and computed values.

In Figure 10 the observed (red dots) and calculated (line) values of the outflow of an HDD-well are shown. The blue vertical bars depict the times of well development. Several well devleopments had to be conducted to achieve a good drainage. In general, the computed results show a very good agreement with the obervations.

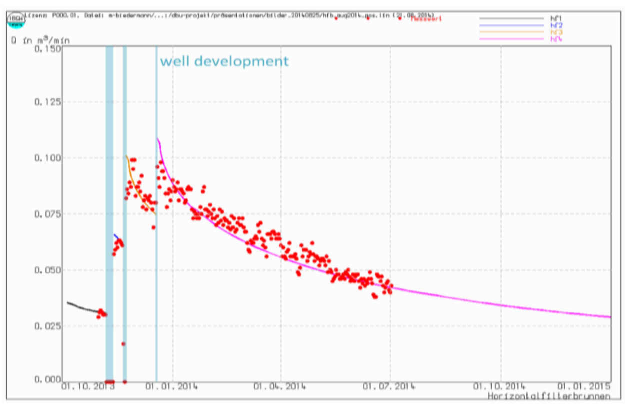

Figure 10 Simulation results (line) of an HDD-well including the head loss process.

Figure 11 a) and b) illustrates the situation in the groundwater at the startup time of the HDD-well. The thick blue line corresponds with the location of the HDD-well in the field test. Several observation points (black dots) are also drawn showing the results of the calibrated groundwater model.

In Figure 12 the groundwater situation is shown nearly 10 months after the startup of the HDD-well. The contour lines represent the groundwater level and show the draw down compared to Figure 11. The 2 circled observation wells are selected for a comparison of observed and calculated values over several months.

That comparison is shown in Figure 12. A very good overall agreement of simulated and measured groundwater levels can be stated.

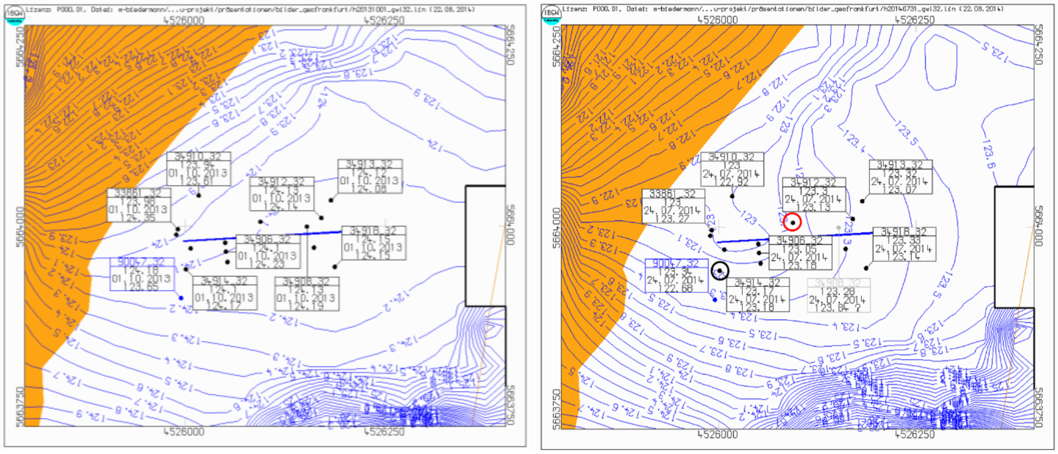

Figure 11a) Groundwater situation at startup of the HDD-well on 10/05/2013.
Figure 11b) Groundwater situation 10 months after startup. Colored circles show the position of 2 observation wells.

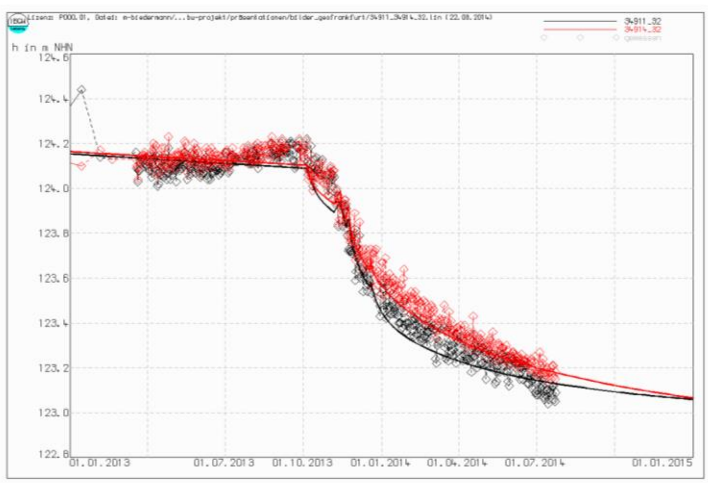

Figure 12 Comparison of observed (circles) and calculated values (line) at 2 different observation wells

CONCLUSION

Processing the data of the structural geological model, a groundwater flow model including a HDD was built up to enable the forecast of the dewatering. Therefore, the program PCGEOFIM, especially suited for mining drainage planning, was used. The calibration was conducted with the information of 28 monitoring wells. For the modeling, results of macroscale experiments regarding the incident flow of the HDD well, and differences between channel and pressure flow were taken into account. The results of several bench scale tests provide the possibility to forecast the dewatering of diverse HDD well configurations and different geological conditions.

Hence, the groundwater simulation suite PCGEOFIM is a tool to allow for the prognosis and planning of HDD-wells using groundwater models.

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