Improving the effectiveness of wells for lignite mine dewatering

Thomas R. Rüde[1], Andre Banning[1], Wiebke Klauder[2], Sebastian Roger[2], Gero Vinzelberg[3]

[1]RWTH Aachen University, Institute of Hydrogeology, Lochnerstr. 4—20, 52064 Aachen, Germany, ruede@hydro.rwth-aachen.de, banning@hydro.rwth-aachen.de
[2]RWTH Aachen University, Institute of Hydraulic Engineering and Water Resources Management, Kreuzherrenstr. 7, 52056 Aachen, Germany, klauder@iww.rwth-aachen.de, roger@iww.rwth-aachen.de
[3]RWE Power AG, Water Resources Management, 50126 Bergheim, Germany, gero.vinzelberg@rwe.com

Abstract Dewatering is a major cost driver in the operation of open cast mines. This is especially the case in the lignite mining industry which has to dewater huge piles of often reduced aquifers with high rates of ochre incrustation. Ochre and filter cake can reduce a planned well discharge by up to 80 %. Maintenance of wells is still lacking a comprehensive and sustainable approach. We have set up an experiment to develop ochre in gravel packs and well screens. The experimental design allows to study the processes of ochre formation in detail and to explore options for rehabilitation.

Key Words open cast dewatering, well clogging, ochre formation, filter cake

Introduction

With respect to investment costs and operating costs, mine dewatering is an important factor in Rhenish lignite mining (including the huge open cast mines Hambach, Inden and Garzweiler). The major cost drivers are the total number of operated wells (some 1,400) and the new wells to be constructed each year (some 180). Therefore, it is decisive that each individual well is exploited as effectively as possible. During recent years, well operation has made some progress regarding efficiency rate and operation with a constant water level. However, figure 1 shows that the actual yield of the open cast mine dewatering wells is mainly limited by the clogging phenomena, well loss and well ageing.

Despite an optimal well operation, the average actual output even of newly constructed wells is only about 50 % of the theoretically possible output. The latter can be determined by analytical well formulas or numerical computations. Based on theoretical considerations and various model

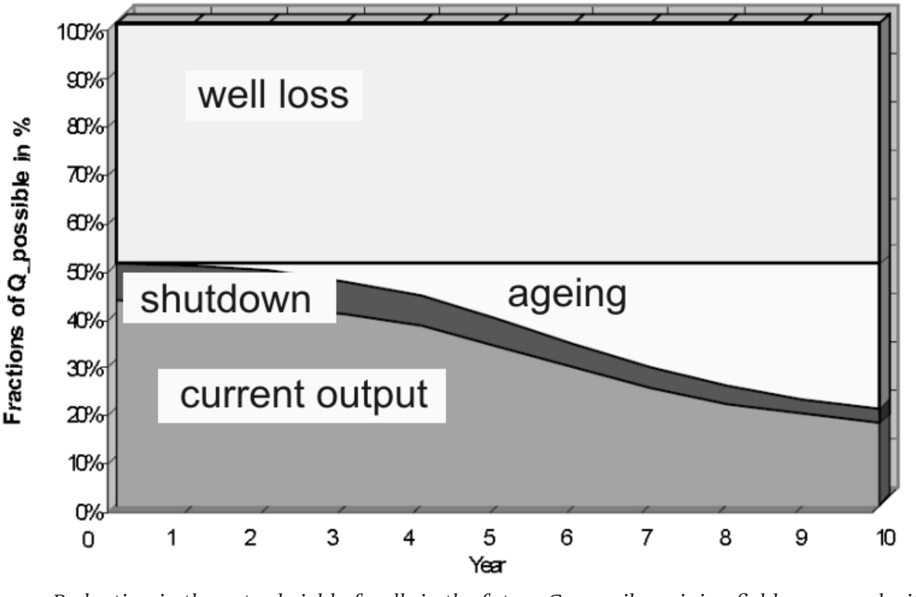

Figure 1 *Reduction in the actual yield of wells in the future Garzweiler mining field compared with the theoretically possible yield*

tests at the Institute of Hydraulic Engineering and Water Resources Management, RWTH Aachen University, and field tests in the Garzweiler mining field, several optimizations in terms of screen type, gravel pack selection and well geometry have been achieved (Klauder et al. 2009). Although theoretical considerations, model and field tests indicate a possible increase in output, this tends to be in the one-digit to low double-digit percentage.

Formation of so-called filter cake (fig. 2) is one reason for reduced specific capacity. When the well is drilled, the drilling mud infiltrates the first centimetres of the surrounding aquifer material to stabilize the borehole. Besides the desired stabilization, the mud seals the borehole wall with a filter cake to prevent large circulation losses during drilling. Although this filter cake usually is a very thin layer, it represents a flow barrier due to its low permeability. In practice, the filter cake is only partially removed during well completion and development, and causes high entrance losses and low well yield. Additionally, particles in the groundwater transported towards the well will not be able to pass and are therefore deposited in the gravel packing. This accumulation of particles decreases the permeability even further and supports well ageing due to iron oxide incrustations. Another way of filter cake formation is physical clogging during well operation as a result of solid particles movement in high velocity groundwater stream. Accumulation proceeds at the interface between aquifer and gravel pack as well as in well screen. These effects depend on groundwater velocity and soil particle size distribution. When performing a long-term and large-scale operation of a multitude of such dewatering wells, one can observe a significant loss of efficiency, above all due to the so-called ageing processes.

Iron oxide incrustations (iron clogging) on the well (screen and gravel pack layer) resulting from a precipitation of particulate, trivalent iron by oxidation of dissolved, bivalent Fe(II) in groundwater are the main reason for ageing (fig. 2). Thus, the well is cumulatively clogged leading to an increased well loss up to complete impermeability. The main influencing parameters of the biochemical reaction are pH-value, oxygen, (turbulent) flow velocities, screen and gravel pack material, groundwater, bedrock composition and type of microorganisms (Houben and Treskatis 2007). This is due to the frequently changing (e.g. in the case of standstills during excavation) groundwater level and the aeration and re-wetting of pyrite containing sediments nearby the filter (although pyrite-sulphur content of up to 0.3 wt.% is comparatively low in the Rhenish mining district; Wisotzky and Obermann 2001).

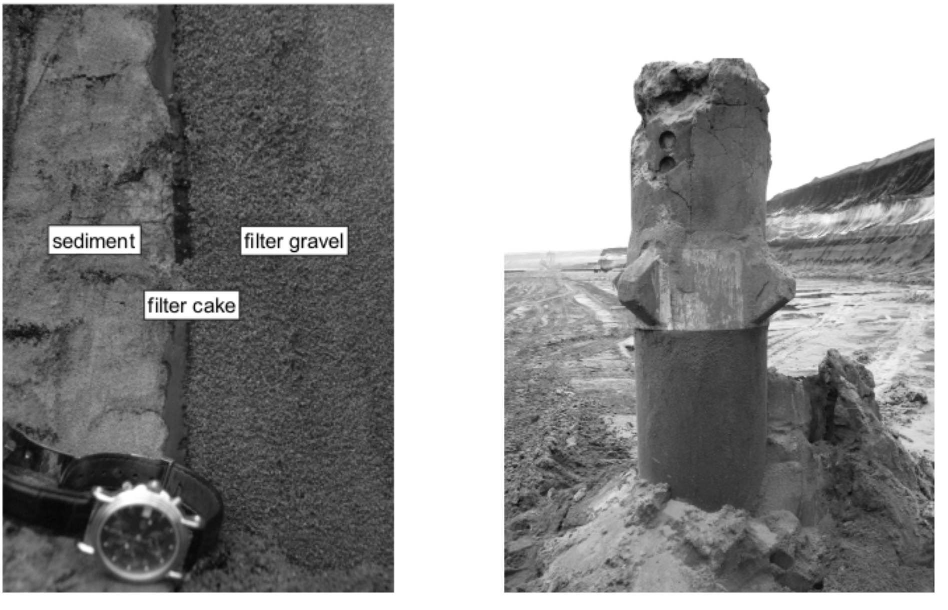

***Figure 2** Example of filter cake (left) and ochre clogging of a well (right), both were excavated after several years in front of the moving edge of an open pit.The screen and gravel pack of the excavated well are coloured totally in orange and red from iron ochre*

Ochre formation is further accelerated in open pit dewatering as wells have long filter lengths in unsaturated sediments allowing for high oxygen flux into the well screens, gravel packs and the surrounding aquifer; an uncommon condition for wells of water works. This entails a further successive reduction in well yield, so that after 10 years, a well only achieves an average 20 % of its theoretical capacity.

The project

Despite the long research on well ochre formation (and also filter cakes), a comprehensive theory is missing. The general influences are agreed on: oxygen, Fe(II), pH, flow velocity, water composition and microorganisms have to be considered (e.g. Sung and Morgan 1980, Ralph and Stevenson 1995, Houben 2006). Nevertheless, there is no agreement on the main controlling factor or the comparative importance of those influences.

We constructed an experimental set-up to study the formation of ochre in different environments. The well screen is of the type currently used in the Rhenish lignite mining district. Also the aquifer material is sampled in one of the open cast mines. In principle, a Fe(II) solution is passed through the materials and will get in contact with oxygen only at the well screen (fig. 3 top right).

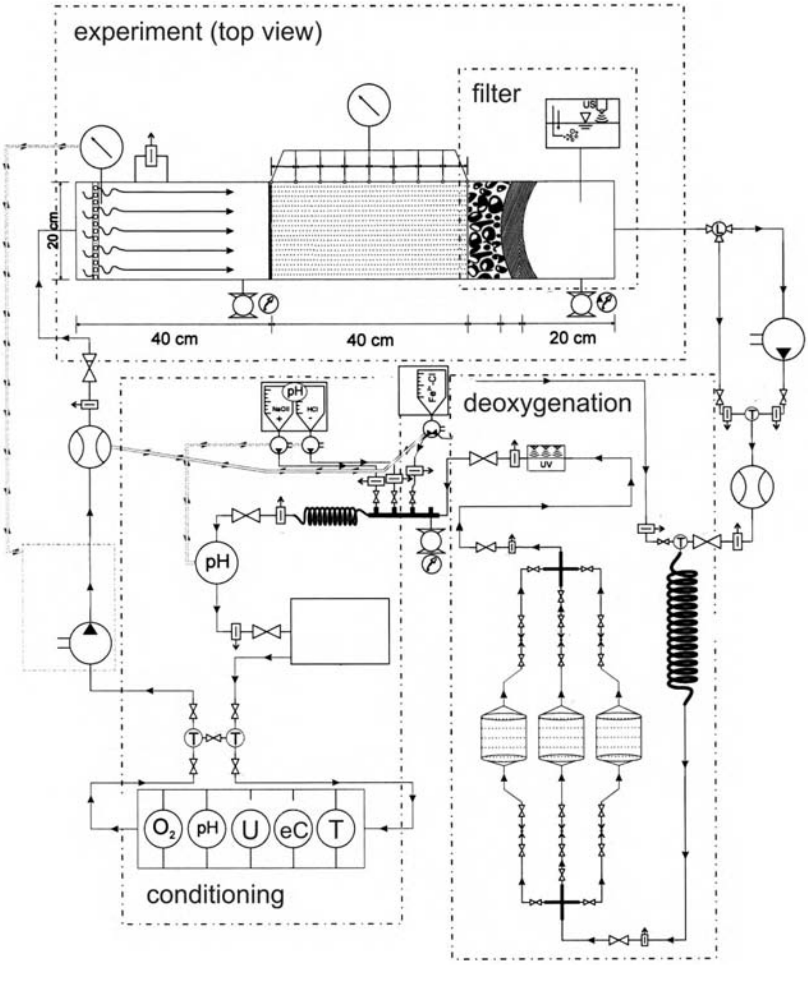

Figure 3 *Set-up of the experimental stage to form ochre in a controlled environment. All instruments are placed on a moveable rack with a size of approx. 2 m³*

The drawing (fig. 3) shows three major units. On top is the flow channel with aquifer material in the centre and the well screen at the right side. Water is flowing through at rates up to 2 L s^{-1}. Water pressure in the aquifer and the water level in the artificial well are continuously measured. Oxygen is supplied in the well. The second unit abstracts oxygen not consumed for Fe(II) oxidation in the well (fig. 3 right). This is accomplished by supplying further Fe(II) and filtration of the formed Fe(III) oxide colloids. The oxygen- and iron-free water is then conditioned for pH and Fe(II) concentration in the third unit (fig. 3 left), whereby also the activity of microorganisms is controlled by ultraviolet radiation. Concentrations of Fe(II) and Fe_{tot} in the model water are measured photometrically at different sampling points in the system.

To avoid any further anions beside hydroxide from autoprotolysis of water, we prepared $Fe(OH)_2$ which is very unstable and cannot be purchased. Following the instructions of Refait et al. (1998), we mixed in a glove box 100 mL of a 0.2 mol L^{-1} $FeCl_2$ solution with the same amount of 0.4 mol L^{-1} NaOH to precipitate 0.2 mol L^{-1} $Fe(OH)_2$ which is quickly dissolved in water to get a Fe(II) solution. After several trials, it became obvious that despite the good yield, the method is not feasible for production of the necessary volume of Fe(II) solution. Reasons for that are the limited space in a glove box, the time needed to prepare several tens of litres of water with an extremely low oxygen content and the thixotropic behaviour of the precipitate making filtration a very cumbersome operation. To conclude, counter-anions cannot be avoided in the ochre experiments. In the case of chloride, water in the experiment has to be refreshed more often, in the case of sulphate or nitrate, effects on the formation of different iron oxides and on the redox potential have to be taken into account.

Conclusions

First results show that Fe(III) hydroxides form in the screen very quickly after the start of the experiment. This is due to the very high Fe(II) concentration of 40 mg L^{-1} used in the first experiments to demonstrate that the set-up enables the controlled formation of ochre. It is critical to keep the pH high (> 7) in the deoxygenation unit to facilitate rapid oxygen consumption to technical zero value, i.e. below the detection limit of the probe (0.1 mg L^{-1}). The filter units retard all Fe(III) colloids. The timing of shutdowns for inspection is yet controlled by the build-up of chloride concentrations in the system. The experimental stage will be used to study abiotic conditions first. These are variations of flow velocity, Fe(II) concentration, sulphate content and alkalinity.

Acknowledgements

The project is fully funded by RWE Power AG and we appreciate the allowance to report about it. We acknowledge the principal investigator of the project, Prof. Dr. Holger Schüttrumpf (IWW | RWTH).

References

Houben G J (2006): The influence of well hydraulics on the spatial distribution of well incrustations. Ground Water 44(5): 668—675

Houben G, Treskatis C (2007): Water well rehabilitation and reconstruction. McGraw-Hill Companies, New York, 391 pp

Klauder W S, Roger S, Adenau W, Müller C, Schüttrumpf H (2009): Durchführung von Filterversuchen – Wissenschaftliche Untersuchung zur Optimierung der Brunnenfilter (Experimental study to optimize well screens) [in German]. bbr 60(6): 40—46

Ralph D E, Stevenson J M (1995): The role of bacteria in well clogging. Water Research 29(1): 365—369

Refait P, Abdelmoula M, Génin J-M R (1998): Mechanisms of formation and structure of green rust one in aqueous corrosion of iron in the presence of chloride ions. Corrosion Science 40(9): 1547—1560

Sung W, Morgan J J (1980): Kinetics and Product of Ferrous Iron Oxygenation in Aqueous Systems. Environmental Science & Technology 14(5): 561—568

Wisotzky F, Obermann P (2001): Acid mine groundwater in lignite overburden dumps and its prevention – the Rhineland lignite mining area. Ecological Engineering 17(2—3): 115—123