Heat storage potential of a flooded mine in the Siegerland-Wied district, Germany

Georg H. E. Wieber[1,2], Hagen Deckert[1], Frieder Enzmann[2], Michael Kersten[2]

[1]*Institut für geothermisches Ressourcenmanagement igem, Berlinstraße 107a, 55411 Bingen, Germany, wieber@igem-energie.de*
[2]*Johannes Gutenberg-Universität, Institut für Geowissenschaften, Becherweg 21, 55099 Mainz, Germany, wieber@uni-mainz.de*

Abstract

In a flooded pit two siderite veins with thickness of 20 m and 5-8 m were mined up to depths of nearly 1000 m. Host rock of the ore bodies is Devonian clay shale. In 1965 the pit was abandoned and careful estimates taking into account the three types of openings revealed buildup of a stagnant water body of approximately 1,000,000 m^3 volume. There is low recharge due to the low permeable host rock with no mine drainage at the deep adit. This renders the mine a huge geothermal reservoir for cooling and heating purposes in combination with heat pumps at the potential benefit of an industrial area planned nearby.

Keywords: flooded mine, stagnant mine water, geothermal reservoir

Introduction

The Rhenish Massif is a Variscan mountain range in the central part of Germany mainly consisting of Devonian schists. Within the area, there are a large number of historical iron and non-iron ore deposits. Mining continued over a period of more than 2500 years but ultimately ceased in 1965. Because of subvertical oriented ore bodies, the underground mining reached depths of more than 1000 m.

In central Europe the geothermal gradient is about 3 °C/100 m. Already during times of active mining, Bornhardt (1912) reported mine water temperatures >20 °C at depths of >500 m below surface in the Siegerland-Wied-District of the Rhenish Massif. Other authors locally detected temperatures up to >30 °C. It is largely accepted that flooded mines can be used for heating and cooling applications with the aid of head pumps (Wieber & Pohl, 2008).

Generally, it appears to be feasible using the geothermal energy of (i) the water drainage, or (ii) the large water reservoir within the flooded mine. Our aim was to investigate one of the mines of the Wied district for its hydrogeological properties and hydrothermal potential.

Geological conditions

In the examined pit, two iron ore veins with thickness of 20 m and 5-8 m, respectively, were mined up to depths of nearly 1000 m. Host rocks of the ore bodies were Devonian shales. During deposit formation highly mineralized water ascended along fractures precipitating ore minerals within the voids and cracks. The mineralization within the steeply inclined veins is dominated by siderite ($FeCO_3$).

The mine was opened up by two transport shafts, one ventilation shaft and 24 deep mining tunnels (Fig. 1). The shafts were worked to 967 m and 907 m depth below surface. The ore veins covered an area of up to 860 m^2 on the 100 m floor, 4790 m^2 on the 600 m adit, and 2060 m^2 on the 800 m floor. During mining activities the veins were excavated completely and the caverns refilled by excavation material. Interestingly, the veins crop out directly on a water divide.

Hydrogeology

The mining area is characterized by a mean surface precipitation of 900 to 1000 mm/a at an average temperature of about 8 °C. Because of the low Devonian sedimentary host rock permeability and the steep slopes, the drainage regime is dominated by surface runoff or/and interflow yielding in a natural groundwater recharge of only up to 25 to 50 mm/a.

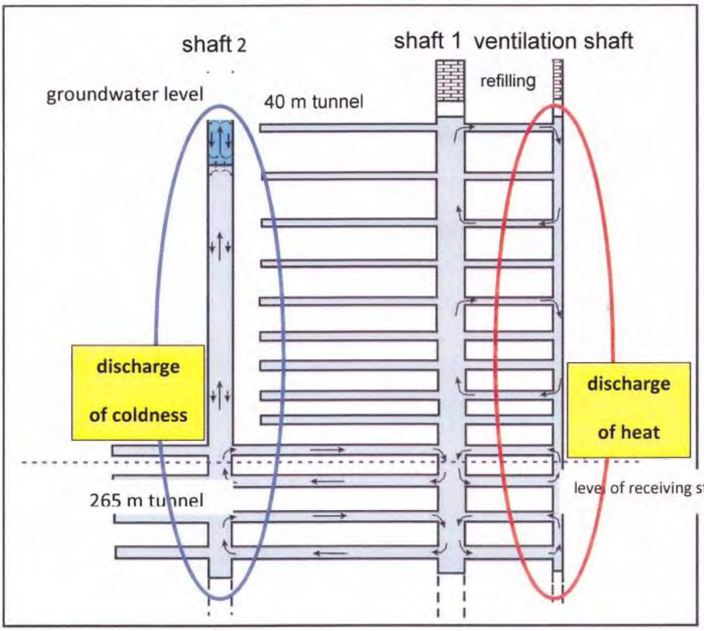

Figure 1 *Schematic diagram of the mine and its potential for a sustainably exploited geothermal storage reservoir*

During mining the groundwater table was lowered by active dewatering. After mine closure and concomitant water level rising, the hydrogeology and hydrology became quite complex because of three different types of permeability influencing the overall flow field. While the hydraulics can be described simply as a communication pipe system defined by the open shafts and adits, there are also high permeable zones of mined veins and other voids with stope fillings.

Laminar and/or turbulent flow is to be expected in such complex hydraulic systems, like Darcy flow and Poiseuille flow (Wolkersdorfer, 2008). Additionally, temperature differences may cause convection at least within the open shafts and adits. Bornhardt (1912) and Heyl (1954) described the dewatering during active mining where Devonian rocks of low storage capacity resulted (usually) in only minor groundwater inflow. On the other hand, the ore veins were characterised by high porosities. Whenever a lode was cut, a lot of groundwater poured into the adits. Groundwater inflow stopped or was reduced when the water reservoir (filling of the veins) were drained off.

Table 1 *Hydrogeological characteristics of the mine*

Geological units	Hydrogeological classification	Permeability	Specific cavity volume
Devonian clay shale	aquitard	low	<0.01
Devonian sandstone	fractured aquifer	low (- middle)	0.01
mined veins (refilled)	pore aquifer	high	0.35 – 0.60
shafts, tunnels, voids	voids	voids	1.0

Already in 2008 and 2009, the groundwater level was found repeatedly at about 105 m below the topographic surface (~400 m NN). That means the groundwater level was still deeper than the deep adit (334 m NN) and the super deep adit (313 m NN). Thus, there must be a permeable zone at approximately 290 m NN which drains groundwater. The mine shaft #1 and the ventilation shaft (Figure 1) were found to be filled up with excavation material from surface to the level of the deep adit. Shaft #2 is the only location which is suitable for groundwater level monitoring/sampling and for in-situ hydrochemical groundwater analysis.

Physiochemical composition of minewater

The groundwater level was measured and/or mine water samples were analyzed at seven different dates. A debris barrier within shaft #2 hampered measurements below a depth of 65 m. Temperature and electric conductivity logs revealed a strong stratification within the accessible first 65 m of shaft #2. The upper layer is characterized by temperatures of 14.2 – 18.0 °C and electrical conductivities of 1.3 – 2.3 mS/cm, while the deeper layer has a temperature of 18.4 – 19.8 °C and a conductivity of 2.5 – 3.0 mS/cm. Generally, the mine water of the deeper stratum is higher mineralized. The change from one layer to the other is very abrupt caused by the different densities and lack of mixing. The hydrochemical composition of the upper layer varies over time, but not that of the deeper groundwater body with alkaline pH-values and anaerobic geochemical environment.

Thermodynamic calculations of saturation equilibria (saturation index) by PHREEQC (Parkhurst et al, 1999) show that the upper water body is undersaturated while the deep water is (nearly) in equilibrium with sulfates like gypsum. Geochemical equilibrations with oxidation zone mineral phases indicate that there is a very minor recharge of groundwater, i.e., the groundwater must be stagnant. The hypothesis of a stagnant water body is corroborated by the fact that there were relatively low water volumes to drain out of the system during active mining, e.g. on the 680 m floor the drainage was only 0.015 m^3/s (Fenchel et al., 1985).

Geothermal potential and resources development

The volume of mined veins can be estimated with nearly 2,000,000 m^3 (Wieber et al., 2011). The stagnant water within the shafts, adits and fillings has a volumne of about 1,000,000 m^3 and a mean temperature of 19 °C. At the final depth of 1,000 m, a rock temperature can be expected of ca. 38 °C, taking into account a geothermal gradient of 3°/100 m. Connective adits/shafts/high permeable zones (mined veins) and convective transport mix the complete stagnant water volume up to 19 °C. This water body is obviously of high geothermal potential. Energy can be extracted from water by use of heat pump technologies. The temperatures can then be increased to a level high enough for heating of buildings. A simple estimation of the maximum thermal energy stored in the water volume and the refillings yields in ca. 40 GWh if to be cooled from 19 °C to 4 °C. In Germany, a one-family household needs about 10 MWh/a for heating. Thus, the stored energy would be enough to heat 400 households for ten years. The geothermal potential of the solid rocks outside the mined veins was estimated by EED-Simulation (Blomberg et al., 2008) for a geothermal borehole field with nearly 2 GWh/a for a period of 100 years.

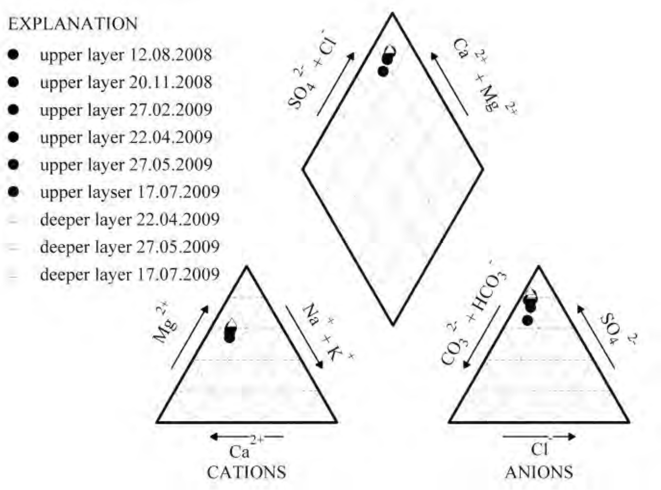

***Figure 2** Piper diagram of mine water shaft 2*

We suggest therefore using the flooded mine as geothermal heat storage because there is only a weak interaction with the groundwater outside the mine (simplified: like a thermos flask). In order to implement storage concepts, the mine must be tapped by shafts or boreholes which serve as extraction and infiltration elements (Verein Deutscher Ingenieure, 2000). The hydraulic system of the extracted and reinfiltrated water can be simplified to a communicating pipe system. A groundwater flow develops automatically from the infiltration point to the pump. The shaft and adit walls serve as an overdimensional heat exchanger of several kilometer lengths (Figure 1). With volumetric specific heat capacities between 1.73 and 5.02 MJ/(m^3K) for the backfills, and 1.31 to 3.52 MJ/(m^3*K) for the Devonian sedimentary rocks, the infiltrated thermal energy will be stored within the flooded mine and the thermal storage utilization ratio is high.

Clearly, this is a strongly simplified calculation. For example, heat recovery due to the natural heat production is not taken into account, and technical aspects of the heating systems are neglected. Further investigations are warranted testing different application scenarios to show more specifically how the temperature field reacts on different heat extraction schemes. The challenge is to find the optimum amount of energy that can be extracted sustainably to supply as much buildings as possible. An alternative operation option ensuring such a steady state sustainability on a certain level is using the mine as a geothermal storage system. Heat from industrial processes and coldness could be stored in the mine and may balance the temperature decrease caused by energy extraction for heating purposes (Figure 1).

Acknowledgements

The authors thank the Ministry of Environment of Rhineland Palatinate for financial support.

References:

Blomberg, I, Claesson, J., Eskilson, P., Hellström, G., Sanner, B. (2008) EED 3.0 Earth Energy Designer - Software within building physics and ground heat storage

Bornhardt, W. (1912) Über die Gangverhältnisse des Siegerlandes und seiner Umgebung – Teil II. Abh. d. Preuß. Geol. Landesanstalt - Archiv für Lagerstättenforschung 2; 444 pp., Berlin

Fenchel, W., Gies, H., Gleichmann, H-D, Hellmund, H., Hentschel, H., Heyl, K. H., Hüttenhain, H., Langenbach, U., Lippert, H.-J., Lusznat, M., Meyer, W., Pahl, A., Rao, M.S., Reichenbach, R., Stadler, G., Vogler, H., Walther, H.-J. (1985) Die Sideriterzgänge im Siegerland-Wied-Distrikt. Geol. Jb., D 77, 517 pp, (Schweizerbart`sche Verlagsbuchhandlung) Hannover

Heyl, K.E. (1954) Hydrochemische Untersuchungen im Gebiet des Siegerländer Erzbergbaus. 72 pp., Heidelberg

Parkhurst, D.L. & Apello, C.A.J (1999) User's Guide to PhreeqC (Version 2) – A Computer Program for speciation, batch-reaction, one-dimensional transport and inverse geochemical calculations. Water-Res. Invest. Report 99-4259, U.S. Depart. of the Interior., U.S. Geological Survey, 326 pp., Denver (Co)

Verein Deutscher Ingenieure (2000): Thermal use of the underground - Part 1 to 3. VDI Verlag, Düsseldorf

Wieber, G. & Pohl, S. (2008): Mine water: a source of geothermal energy – examples of the Rhenish Massif. – In: Technical University of Ostrava Faculty of Mining and Geology [Hrsg.]. In: Proceedings of the 10th IMWA Congress (International Mine Water Association) 02.06. - 05.06.08 in Karlovy Vary, Czech Republic: 113-116 pp., Karlovy Vary

Wieber, G., Pohl, S., Landschreiber, K. & Streb, C. (2011) Geflutete Grubenbaue als Wärmespeicher. In: bbr-Fachmagazin für Brunnen- und Leitungsbau, 5, p. 34-40, Bonn

Wolkersdorfer, C. (2008) Water Management at Abandoned Flooded Underground Mines. 465 pp., Berlin