Pump Tests in Deep Ore Mine Shafts for the Evaluation of a Possible Geothermal Use

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Abstract

Mine water of deep abandoned and flooded ore mine shafts are suitable for geothermal use. In the presented case (Germany, Rhineland-Palatinate), geothermal water is pumped from a shaft of the San Fernando mine into a shaft of the Friedrich-Wilhelm mine. Further use is planned in the outlet of the Wolf mine. For this purpose both a sufficient water inflow and outflow must be guaranteed. In the years 2018 to 2019 the suitability of the shafts were tested by a long-term pumping test. The water level in San Fernando shaft reacts only marginally to water withdrawal, while the water level in Friedrich-Wilhelm shaft and in the outflow Wolf fluctuates considerably.

Introduction

The Rhenish Massif was an important ore mining district with shafts reaching local depths of more than 1,000 m. The ore deposits of the Siegerland are spread over hundreds of individual veins. An economic extraction was only possible for individual mines that had sufficiently large deposits (Gleichmann 1990). In the middle of the last century individual mines were combined to form large composite mines. The individual mines were connected to each other in depth by adits several kilometres in length. So the mining could be continued in some compound mines until 1965 (Fenchel et al. 1985). After closure the underground workings were flooded and groundwater filled the mine shafts. This created large water reservoirs in the underground which can be used for geothermal heat extraction or heat storage. There are more than 500 abandoned mines in the Siegerland-Wied district, and they have considerably altered the large-scale hydrogeological properties of the subsurface in this area (Fenchel et al. 1985). The widespread Devonian silt and sandstones in the area unaffected by mining typically have low permeability (Wieber et al. 2011). In contrast, the backfilled mine workings have increased hydraulic conductivities. Mine water in neighbouring shafts is often connected by laterally extended underground developments (Wieber et al. 2019). The tunnels and shafts, together with the mining areas, have created permeable areas in which mine water can flow with high velocity. Heat circulation is likely in these mines, and heat conduction across the large rock–water interfaces in the mine workings is expected to replenish heat rapidly after exploitation.

In Herdorf (Fig. 1) two geothermal uses are planned or in operation. In the Sotterbach valley, a geothermal plant is operated with mine water. Water is pumped from shaft 2 San Fernando and infiltrated into shaft 2 Friedrich Wilhelm. Further geothermal utilisation is planned at the outflow of the Wolf mine. Against this background, different quantities of water have been pumped and infiltrated from the above-mentioned shafts in recent months.

The composite mine originally consisted of five initially separate iron ore mines, namely Wolf, San Fernando, Friedrich Wilhelm, Füsseberg, and Glaskopf. The mines were later connected by deep drifts or crosscuts (Fig. 2).

The Wolf Mine comprises the main shaft, a blind shaft, an old shaft (not shown in Fig. 2), and 16 further levels below the lowest mine adit, the "Tiefer Stollen" (Fig. 2). The San Fernando Mine has two main shafts to depths of 675 and 1002 m, and a 340 m deep blind shaft connecting the five lower mine

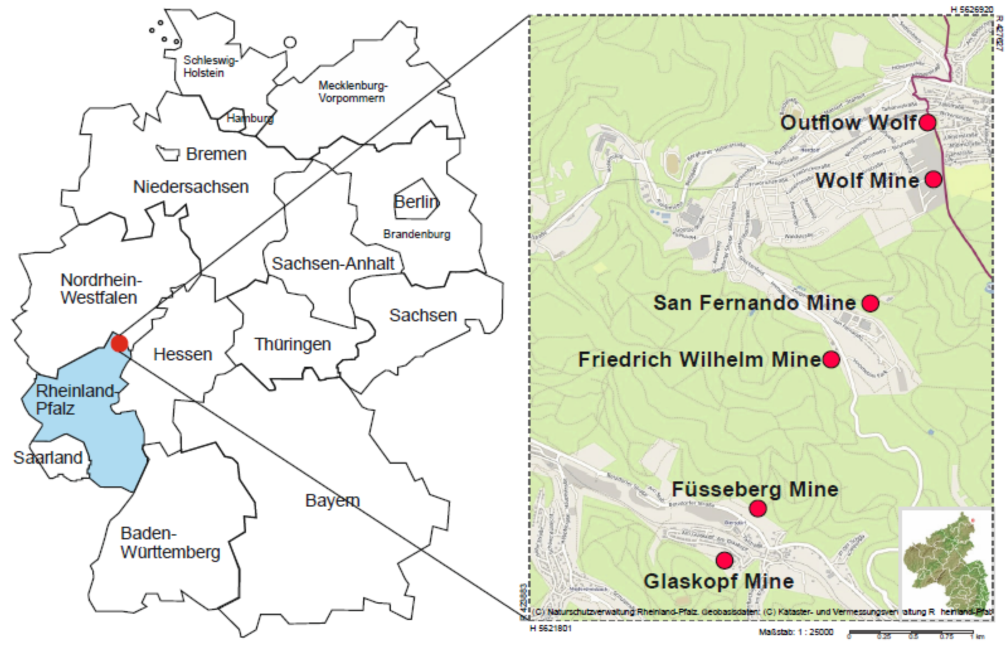

Figure 1 Location of the mine.

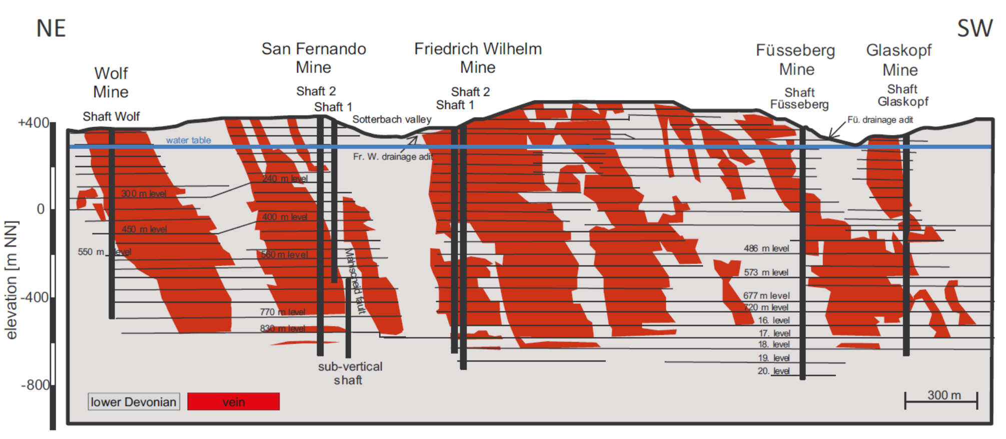

Figure 2 Schematic diagram of the Wolf, San Fernando, Friedrich-Wilhelm, Füsseberg and Glaskopf mine workings (according to Streb 2012)

levels. Both mines are connected between the 560 m and the 770 m level. The 240 m level of the San Fernando Mine is connected by a decline with the 300 m level workings of the Wolf Mine. Another connection exists between the 450 m level of the Wolfsmine and the 400 m level of the San Fernando mine. Other connections between the two mines are through galleries below 550 m, from which there is a hydraulic gradient towards the Wolf Mine shaft. The mine shafts #1 and #2 of the San Fernando Mine (Fig. 2) are filled with backfill material from the surface to the "Tiefer Stollen". Between the mines San Fernando and Friedrich-Wilhelm there is only one connecting adit between the 830 m level (San Fernando) and the 17th level (Friedrich-Wilhelm). Connections between the Friedrich-Wilhelm mine and the Füsseberg mine exist between the 486 m level and the 18th level. The connections of the entire system are verified by tracer tests.

Streb (2012) estimated the water volume of the Wolf Mine shaft at 6,700 m³, while the total volume of the San Fernando Mine shafts is approximately 26,500 m³. The shaft volumes of the Friedrich Wilhelm, Einigkeit, Füsseberg, and Glaskopf mines account for about 70,000 m³ in total (Wieber et al. 2019).

Methods

For the operation of the geothermal plants, mine water is pumped from the San Fernando shaft into the Friedrich-Wilhelm shaft after heat extraction or heat supply. Effects such as the water levels in the shafts and the water quantities in the Wolf outlet must also be determined because there is another geothermal plant planned. A still running long-term pump test started in April 2018 was carried out for this purpose. Information are collected by using data loggers which are installed in San Fernando Shaft 2, Friedrich-Wilhelm shaft 2 and in the outflow Wolf. In addition, manual measurements were done weekly by means of electric contact gauge. The pumping test was carried out with a water withdrawal of 8 L/s at the beginning over 12 L/s to 16 L/s at present.

Results

Even before the start of the pumping test, a comparison of the water leakage of the wolf mine and the water levels in the Friedrich-Wilhelm shaft shows that these are 2 sensitive systems that response in a similar way. When the pump power is switched on or changed, both systems react abruptly. There is a slight lowering of up to 0.2 m of the water level in the pump shaft and a simultaneous increase of up to 1,9 m in the injection shaft Friedrich-Wilhelm (Fig. 3). After switching off the pump, the water levels react vice versa.

The Wolf outflow also reacts directly to the switching on or off of the pump. When the pump is started, the flow rate drops sharply and then rises again while pumping stops. As the duration of the pump test progresses, however, the flow rate recovers somewhat. With a pumping capacity of 8 L/s (April to July 2018) no stationary state occurs at the Wolf outflow. With the increase of the pumping capacity to 12 L/s (July to August 2018) and 16 L/s (September to October and November to December 2018) a stationary state seems to be reached in each case by outflow rates of approximately 3.5 L/s respectively 1.5 L/s and 2.5 L/s.

However, it should be noted that 2018 was an unusually hot and dry year in Germany. The mean precipitation (2000 to 2015) in the Siegerland-Wied district is 1,056 mm/a, and the annual average temperature is 8.0 °C (Deutscher Wetterdienst climate station Bad Marienberg). The mean precipitation in 2018 was 787 l/m², the annual average temperature 9.4 °C.

Conclusions

As the pumping capacity from the San Fernando shaft increases, the amount of water at the outflow of the Wolf mine decreases,

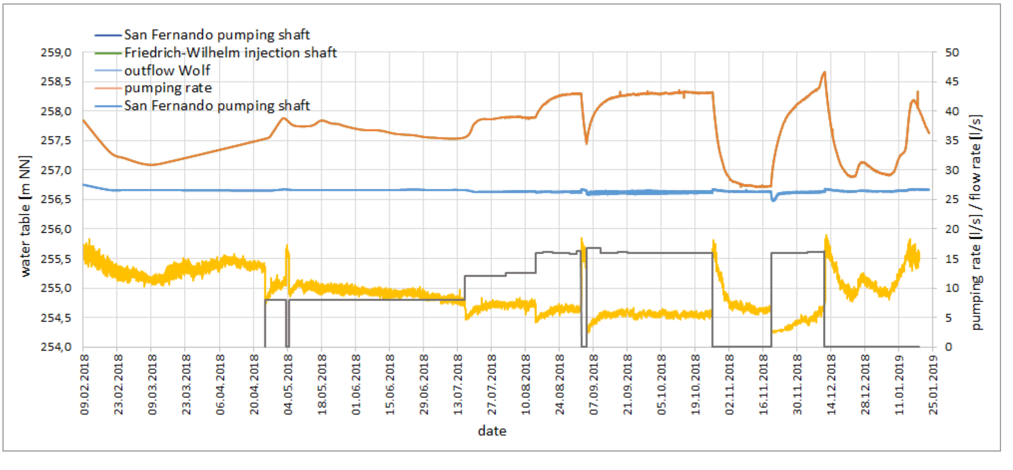

Figure 3 Schematic diagram of the measured values

while the water level in Friedrich-Wilhelm shaft rises. It is therefore necessary to carry out additional evaluations of the hydraulic connection between the San Fernando - Wolf and Friedrich Wilhelm - Füsseberg - Glaskopf composite pits. The two composite mines (Fig. 2) are connected only by the 830 m underground level (San Fernando) and the 17th level (Friedrich-Wilhelm). The connecting adit traverses the "Mahlscheid" fault, which was already identified at the beginning of the investigations as a possible weak zone. It can be assumed that the entire system drains water via the Wolf outflow, since no drainage takes place in the outlet of the Glaskopf mine. Another outflow in the area of the Glaskopf mine could not be detected despite intensive search. It is possible that the outflow via the Devonian mountains into the Heller will take place.

All in all, this is a mine water system that reacts sensitively to changes. A hydraulic connection between the two composite mine via the 830 m level (or 17th level) appears to be limited. Further investigations to optimise the system by increasing the pumping capacity and later by reversing the pump and injection shaft are planned.

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