First hand experience in a second hand borehole: Hydraulic experiments and scaling in the geothermal well Groß Schönebeck after reopening

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Abstract

Stimulation procedures applicable to great depths are needed for geothermal electricity generation in Germany. More than 50 former oil and gas exploration wells in northeast Germany were screened to select an abandoned well to install an in situ laboratory for hydraulic experiments. Technical feasibility of renewed access and temperatures of 130-140ºC at the bottom were the criteria for selection. The 4240 m deep well Groß Schönebeck 3/90 was picked out. It was abandoned soon after completion in 1990. Access was gained in 2000, by drilling through only a few hundred meters of cement, because the sections between cement plugs were filled with drilling mud. This operation required a fraction of the costs for a new well. Furthermore, the well was deepened to 4294 m. Since, two intervals of the Rotliegend sandstones were hydraulically stimulated in January 2002. After a moderate pumping test over several weeks, scaling began to occur with the precipitation of native metals from the brine. Another set of open-hole stimulation experiments is planned for 2003.

Keywords*: reopening exploration wells, stimulation experiments, scaling problems.*

1 Introduction

Most geothermal power plants and heating stations in Germany and elsewhere are built at geothermal anomalies, where an aquifer with sufficient porosity and permeability provides the hot water. Drilling deep enough can usually attain required temperatures. Although drilling is costly, it is generally the flow rate (i.e. the permeability) from the reservoir that dictates the technical feasibility of exploitation. Exploitation may be precluded by low permeability, unless it can be enhanced with appropriate stimulation procedures (Hurter et al., 2002).

Geothermal electricity generation becomes worthwhile at temperatures above 100ºC and flow rates of at least 50 m³/h. Such temperatures are found at depths in the order of 3000-4000 m in much of the North German Basin and large areas worldwide. Permeability to accommodate high flow rates is rare in this depth range. The development of technology to increase the permeability of deep aquifers by hydraulic fracturing or stimulation is best done in a down-hole laboratory. With the ability to stimulate a variety of rocks geothermal energy can be exploited where it is needed.

2 Geological background

2.1 Choosing the site

A site in the North German Basin was selected to develop this technology, because it contains widespread low permeability rocks that attain temperatures necessary for geothermal power generation. It is fairly well known due to gas exploration activities and a large consumer population lives on it.

The North German Basin is part of a large basin system extending across Europe from the North Sea into Poland. It is filled with up to 10 km of sediments. Deposition began with extrusive rocks up to 2000 m thick covering large areas of the basin. These ~300 Ma years old volcanic rocks consist of rhyolites, ignimbrites, andesites and, to a lesser extent, basalts (Breitkreuz and Kennedy, 1999; Benek et al., 1996). A clastic sequence (Early Permian Rotliegend) of aeolian sandstones, fluvial fans as well as playa deposits covered the volcanic rocks. Then up to 4000 m of cyclic evaporites and carbonates were deposited (Late Permian Zechstein). Large lateral thickness variations were caused by salt diapirism during Late Cretaceous, strongly affecting the temperature field.

Geologic formations suitable for our studies have: (1) temperature above 120°C, (i.e. depth >3000 m); (2) large regional extent (to extrapolate results of one site to other areas) and (3) a variety of lithologies for investigation. The Rotliegend formation fulfills these requirements. It comprises clastic siltstone and sandstone layers generally overlying extrusive volcanic rocks.

Geological and technical drilling information on 50 deep former oil and gas exploration wells in northeast Germany was scrutinized to select an abandoned borehole suitable to serve as an in-situ laboratory for hydraulic experiments in the Rotliegend. The 4240 m deep well Groß Schönebeck 3/90 was chosen (Fig. 1a).

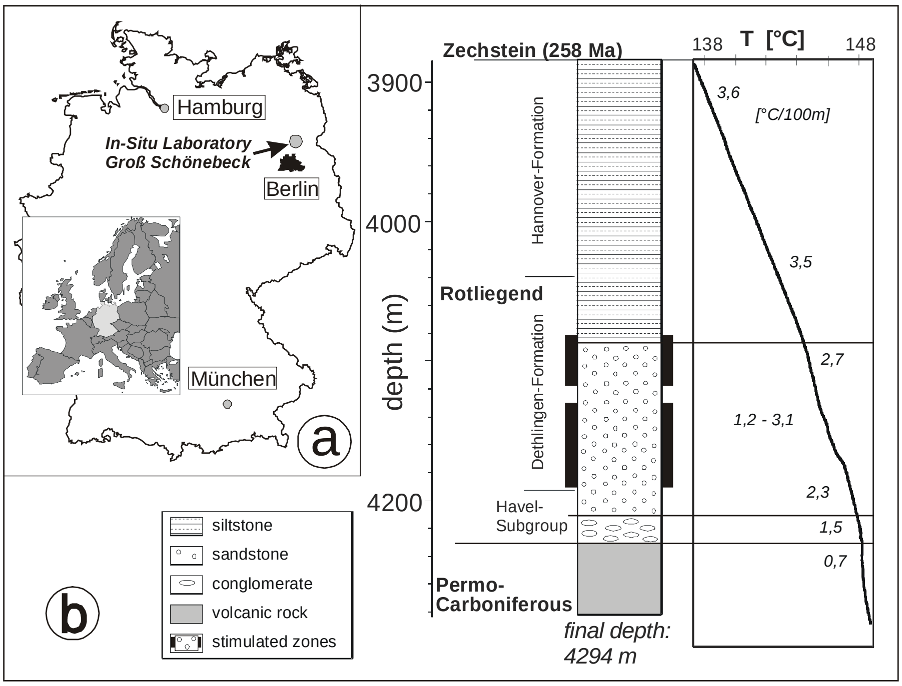

Figure 1: a) Location of the well Groß Schönebeck 3/90. b) Stratigraphy, lithology and vertical temperature distribution of the open-hole interval.

2.2 The abandoned well Groß Schönebeck 3/90

Groß Schönebeck 3/90 was drilled in 1990 for gas exploration. It was cased down to 3880 m depth and 360 m were left open. This well cuts through 2370 m of Quaternary to Triassic sediments followed by 1492 m of Upper Permian Zechstein evaporites reaching the Lower Permian Rotliegend at 3881.8 m and bottoming in Permo-Carboniferous andesites at a depth of 4240 m (Fig. 1b). The Rotliegend at this location can be divided into 3 major sections from the top down: siltstones (203 m), sandstones (146 m with 19 m of basal conglomerate) and two thin andesitic flows (9.5 m). Geophysical logs (caliper, gamma-ray, resistivity, induction, spectral-gamma, sonic, dipmeter) as well as abundant porosity (290 samples) and permeability measurements (109) on cores are available. Not enough gas was found so the well was closed with 3 cement plugs separated by sections filled with drilling mud and abandoned. The well was secured with a concrete plate covered with earth. The documentation to assess the technical condition of the well (casing, cement, open-hole) was the drilling report (EEG, 24.05.91) and the plugging report (EEG, 22.01.91).

3 Reopening the well in 2001

3.1 Drilling operations

An area of 70 m x 45 m was cleared and leveled for the drilling pad. A special permit from the forestry office had to be procured to remove tree cover. A new cellar was dug around the well and lined with concrete. A new casing-head was welded on to the old (9 5/8“) casing. A drilling rig was set up. No open pits are allowed (zero discharge policy) spent fluids had to be stored in closed tanks and then properly disposed of.

The largest uncertainty when re-opening abandoned wells are non-documented materials (fish, junk) that remains in the well (drill bits, packers, miscellaneous tubings, pipe sections, etc.). Re-opening Groß Schönebeck had practically no such surprises in store. At a depth of 16,8 m, a piece of metal (10,5x3 cm) wrapped itself around the bit, but was removed without causing damage.

The location of the cement plugs differed from that stated in the documentation. Positions were shifted up or down hole from 4-18 m and thickness was 47 m less to 14 m more than recorded.

Intervals between cement plugs filled with old drilling mud were expected to be easily passable by the drill stem. However, in some intervals, drilling had to be activated (from 511-538 m and from 1755-1759 m in the 9 5/8“ casing as well as from 2348-2366 m and from 2396-2500 in the 7“ liner). Probably the cement was not properly placed everywhere. As soon as the open formation was reached, work had to be continued under gas protection (blowout preventer). The open-hole section was worked over with a slightly wider drill bit to remove old mud cake. Old drilling mud was re-utilized and reconditioned, as needed helping to reduce costs. Upon reaching the bottom of the well, the volcanic section was drilled for ~ 50 m at a pace of 0,7 to 1,0 m per hour. Mud loss of 41,7 m^3 occurred in the bottom of the sandstones and in the volcanic section. This happened after the drill stem got stuck.

3.2 Complications

The drill stem got stuck at 4168 m. Factors contributing to differential sticking were: tight set- up (120,3 mm diameter drill stem in a 149,2 mm borehole), drill mud loss, the employment of cylindrical collars instead of spiralled drill collars and the deviation of the well at that depth (201 m at 3874 m).

Pulling the drill stem (load of 120 t) as well as combined pulling and twisting proved useless. Decreasing the density of the mud by adding fresh water did not help either. As mudflow was not interrupted, 1,8 m^3 of a special Spotting Fluid (PIPE-LAX ENV. from MI Drilling Fluids) could be circulated to the critical depth. This water soluble and environmentally compatible fluid migrates into the mud cake between borehole wall and stuck drill stem, releasing it after about 20 – 24 h. At half hour intervals renewed pulling and twisting (110 t load) was attempted. It took 17 h since adding pipe-lax to free the drill stem by pulling it a load of 137 t (< drill stem critical load). The cylindrical collars were exchanged for 120,6 mm (4 ¾") spiraled collars. As a precaution a jar device was incorporated in the drill stem. Drilling resumed without further incidents.

4 Summary of operations after reopening

Hole and casing survived drilling, logging and sampling runs at several ocasions over a time span of 10 years.

In January 2002, two Rotliegend sandstone intervals (4130-4190 m and 4081-4118 m) were hydraulically stimulated. The classical oil/gas fracturing concepts followed, except that stimulation was in the open-hole instead of through perforations in a casing. This includes the use of packers (top) and sand plugs (bottom) to isolate the treatment interval and employment of high viscosity fluids (polymers) and proppants. After stimulation, the production rate measured during a casing lift test was 25 m^3/h, an increase by a factor of ~ 3.6 from an initial value of 7 m^3/h. As a consequence of these short, but intense, activities slight changes occurred in the caliper logs including a few new small enlargements. It was also noticed that material has been deposited at the bottom of the well, decreasing the total accessible depth of the hole. This fact was not considered surprising after so many manipulations in the open-hole.

After the stimulation experiments a moderate production test was carried out over several weeks. A down-hole pump was installed at a depth of 330 m to extract formation water at a rate of approx. 1 m^3/h over several weeks. At steady state conditions the productivity-index achieved was 0.6 m^3/h * MPa. A total volume of 700 m^3 fluid was hauled out.

It was after this low intensity, but long duration, pumping experiment that more dramatic changes were noticed, which are described in the following.

5 Scaling

First hints of authigenic scaling were noted while dismantling the pump. The top of the pump, casing and cables were covered with a gray mud. X-Ray Diffraction analysis (XRD) of this material revealed that it was made up of native lead, laurionite ($Pb(OH)Cl$) and halite ($NaCl$). Minor amounts of malachite ($Cu_2CO_3(OH)_2$) and traces of barite ($BaSO_4$) were also identified.

Bailer runs hauled solids from the bottom, consisting of rock fragments, quartz grains, proppants and miscellaneous metallic particles. The microscope displayed dendritic copper aggregates up to 2 mm long. At higher magnification characteristic surface structures of copper crystals became visible, proving the authigenic origin. The mineralogical composition of the bailer samples (XRD) comprises as major phases native copper, native lead and barite. Minor amounts of calcite ($CaCO_3$), a rare earth element fluoride (CeF_3) and traces of galena (PbS) were also detected. Additional mineralogical investigations are still under way.

Since these scaling phenomena were observed for the first time in the borehole after deploying and running the electrical pump, we believe that the precipitation of this material was likely induced by electrochemical and/or streaming kinetic processes initiated by the pumping experiment. Understanding this process is critical for planning future experiments and later for designing sustainable exploitation strategies of similar brines.

Logging data of redox potential (RX) and electrical potential (EP) are available from 260 m depth (water level) down to 2800 m depth and down to 4280 m, respectively. A logging tool developed in the KTB project (Winter et al., 1991) was employed 42 days after cessation of the pumping test. Electrical potential is stable at about -100 mV in the cased section. In the open hole section (3840 m to 4200 m) it drops down steeply to -700 mV. This potential difference in combination with water flux during the pumping test is a possible reason for the authigenesis of native metals and minerals out of the brine (Fig. 2).

The redox potential decreases exponentially with depth. It represents a sliding transition from oxidizing to reducing conditions in deeper sections of the borehole. A redox potential drop from 260 to 900 m interrupts this trend, where locally reducing conditions in the borehole fluid are encountered. We interpret the anomaly in the section from 400 to 800 m depth as caused by degassing of the fluid. The pronounced reducing environment between 260 and 320 m depth may be caused by lead scalings on the casing wall, originated by electrochemical and/or streaming kinetic processes (Fig. 2).

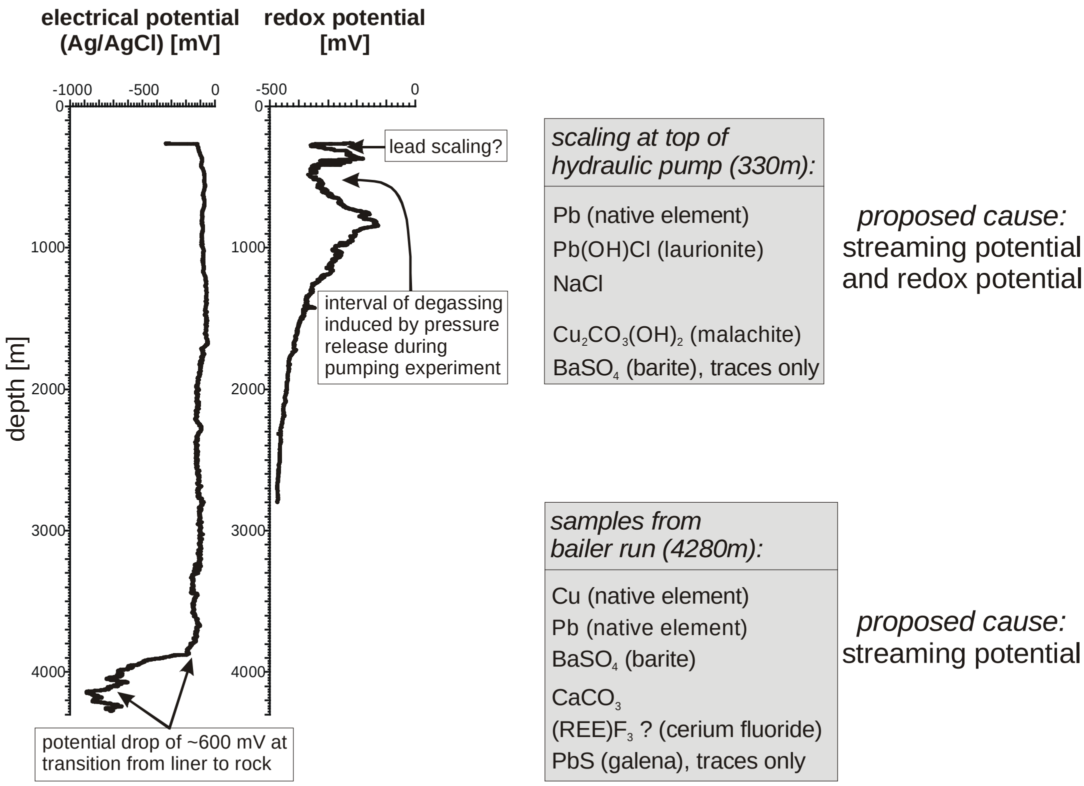

Figure 2: Electrical potential, redox potential logs of the well Groß Schönebeck 3/90 and possible reasons for the formation of native metals and minerals.

6 Recommendations/Conclusions

Considerable information exists on abandoned wells. It is useful information, but one must resist being lulled into a sense of security of what can be expected, because not all information is contained in the detailed reports. We have greatly benefited from the contact with technical personel (now retired) that were present at the first drilling phase.

The idea of a *second* hand well is seductive to the following state of mind: the well was drilled a first time, so the second time there will be no surprises and standard procedures can be applied. This attitude could have cost us the well (see differential sticking). Expect surprises and plan for additional measurements!

The unexpected scaling phenomena have to be understood. This is very important for operating geothermal power plants under similar geological environments.

Second hand boreholes are worthwhile. Re-opening them costs little compared to drilling a new one. Reopening the well Groß Schönebeck 3/90 cost about 15% of a new well.

Acknowledgements

This multidisciplinary project is a joint venture of research institutes (GFZ Potsdam, BGR Hannover, GGA Hannover), Universities (TU Berlin, RU Bochum, U Stuttgart) and industrial partners (GTN Neubrandenburg, BWG Neubrandenburg, MeSy Bochum). BMWi, BMBF, BMU, MWI and MWFK (Federal and Brandenburg State Ministries of Economy, of Research and Education, of the Environment) fund the project.

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