GEOTHER

Source: cleanwells GbR

A description of the operation of the geothermal energy storage wells over a ten year period focusing on their maintenance and rehabilitation which is based on intensive monitoring.

In diesem Artikel warden die zehnjährigen Erfahrungen im Betrieb der stickstoffbeaufschlagten Kältespeicherbrunnen vorgestellt, die auf einem intensive Monitoring beruhen. Einen Schwerpunkt bilden dabei die durchgeführten Regenerierarbeiten.

MAL ENERGY STORAGE SYSTEM

at the Parliament buildings in Berlin – Operation, monitoring and rehabilitation of N_2-charged groundwater wells

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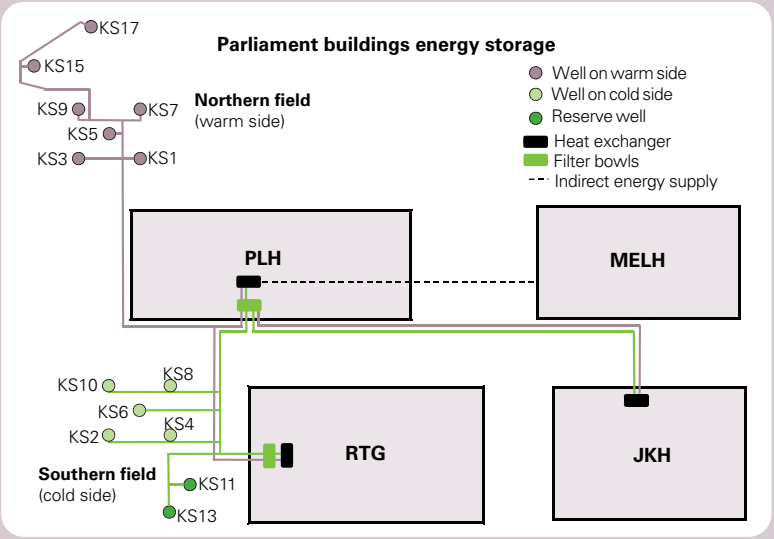
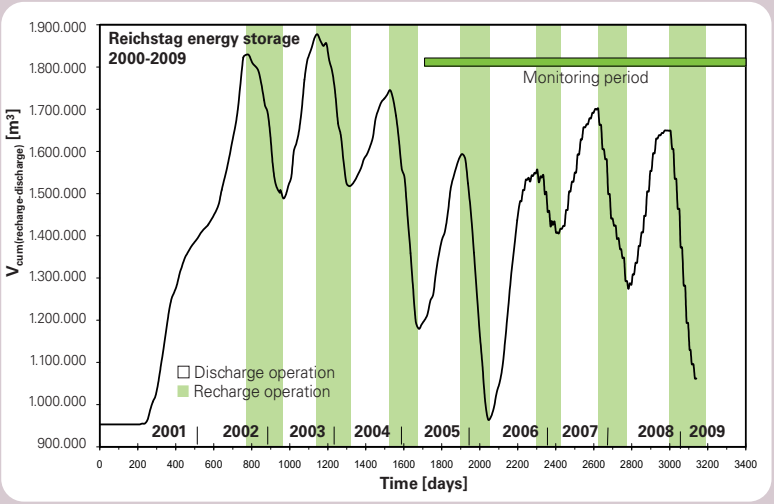


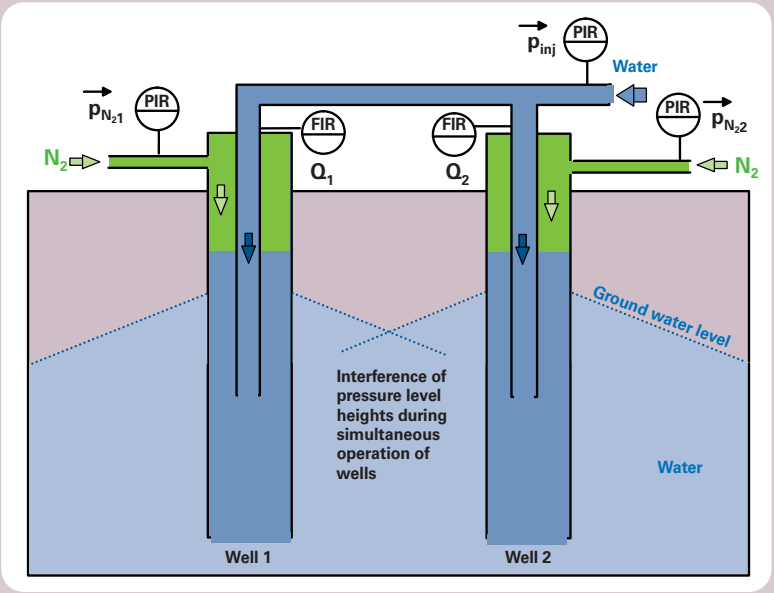
Source: Geothermie Neubrandenburg GmbH

Abb. 1: Schematische Darstellung des Kältespeichers. PLH = Paul-Löbe-Haus, RTG = Reichstag, JKH= Jakob-Kaiser-Haus, MELH= Marie-Elisabeth-Lüders-Haus



Source: Geothermie Neubrandenburg GmbH

Abb. 2: Das kumulative Volumen des Kältespeichers, Betrieb 25.08.2000 – 28.2.2009 Einspeicherbetrieb – thermisch abgekühltes Wasser wird eingespeichert, Ausspeicherbetrieb – Wasser der „warmen" Seite wird zwecks Klimatisierung ausgespeichert



Source: Geothermie Neubrandenburg GmbH

Abb. 3: Schematische (stark vereinfachte) Anordnung zur Bestimmung der Ergiebigkeit eines Kältespeicherbrunnens für das System entsprechend dem Stickstoffdruck

The air-conditioning system of the parliament buildings in Berlin is operated by means of geothermal wells which use 0.6 M m³ of groundwater annually. The „cold side" of the system is provided by seven wells in the southern well-field and the 'warm side' is provided by another seven wells in the northern well-field. During the summer half-year groundwater is abstracted from the designated „cold side", warmed up in the air-conditioning system and injected back into the designated „warm side" of the aquifer. In turn the groundwater from the warm side is pumped out, cooled in the roof cooling units and stored in the cold side during the winter months.

Geology and Hydrogeology

The geothermal wells at the Reichstag abstract groundwater from the Berlin „sandbox" which is a typical stratum in Berlin. Glaciofluvial fine sands of the late Saale ice age and Weichselian valley sands overlie the till of the Saale ice age (Warthe stadium). These glacial valley deposits have eroded away both the older sediments and also partly the Warthe till. Laminary peat and/or meadowlike loam formations covered by 2 to 4 m fillings of sand, gravel and construction waste were found near the surface.

The sands and gravels of the Saale ice age which underlie the till also form an aquifer. The till which lies between these sands and gravels (the Berlin „sandbox") represents a remarkable aquitard in the investigated area as it hydraulically separates the two aquifers from each other. In the southern field („cold side") the till was absent in areas. This is of particular importance as it means that there was no continuous aquitard forming a barrier between these aquifers here.

The coefficients of permeability of the various horizons were determined by means of particle size distribution analysis. This testing showed that the individual horizons even within the same aquifer varied significantly. The till (the aquiclude) exhibited permeabilities ranging from 9.6×10^{-8} to 2.0×10^{-7} m/s and the aquifer beneath it (the Berlin „sandbox") demonstrated permeabilities between 1.1×10^{-4} and 2.3×10^{-4} m/s. A layer of silty fine sand was found in one area of the

northern field at a depth of 38 to 42 m with low permeability values ranging from 5.3 x 10^{-5} to 7.8 x 10^{-4} m/s. The silt content of the sands and gravels increased towards the underlying layer of the till which caused a decrease of the permeability to 9.6 x 10^{-5} also here.

The groundwater within the aquifer is confined and the piezometric water level lies approx. 2 m below ground level. In the area of the geothermal energy storage the groundwater flows towards the river Spree, however, the groundwater velocity and the gradient of the aquifer are low.

Construction and operation of the geothermal energy storage system

As the use of geothermal energy has proved to be an alternative method for obtaining low temperatures with economical and ecological advantages this technology was designed and installed for the air-conditioning of the parliament buildings in Berlin. The Reichstag RTG, the Paul-Löbe Haus (PLH) and the Jakob-Kaiser Haus (JKH) are directly connected with the energy storage and the air-conditioning system of the Marie-Elisabeth-Lüders Haus (MELH) is supplied via the JKH **(Fig. 1)**.

A total of twelve boreholes were drilled between 1996 and 1998 for the construction of the geothermal storage system to a depth of 60 m. The various parliament buildings were then connected with pipes above ground to these wells. The complete system was commissioned in 1999 and incorporated ten active wells with an additional two wells to be kept in reserve. The system was extended by two further boreholes in 2009.

Groundwater at a temperature of 6°C to 10°C is abstracted from the southern well-field (the „cold side") during the summer months. The air-conditioning system of the parliament buildings is operated by passing this cool water through the heat exchangers above ground. The water which has been warmed up to a temperature of 15°C to 30°C (average of 22°C) after it passes through the system is then injected into the northern well-field („warm side"). Prior to reaching the heat exchanger the groundwater is cleaned in four filter bowls located in the PLH and the RTG containing between eight to 16 filter bags with a mesh size of 10 µm to 20 µm. In the winter the operation mode of the system is reversed. The „warm" water is abstracted from the northern well-field and is cooled down in roof cooling units in the MELH. Following use this is injected into the wells of the southern well-field at a circulation rate of approx. 300 m³/h.

Until autumn 2002 the system had exclusively been used for cooling with a total volume of nearly 2 M m³ groundwater having been abstracted to operate the air-conditioning. In winter 2002/2003 the system was extended to store also the ambient cold produced by the roof cooling units and thus to date the temperature abstracting and discharging varies seasonally. Approximately 0.6 M m³ groundwater is annually abstracted and re-injected whilst the seasonal quantities stay nearly identical in the long run **(Fig. 2)**.

Source: Geothermie Neubrandenburg GmbH

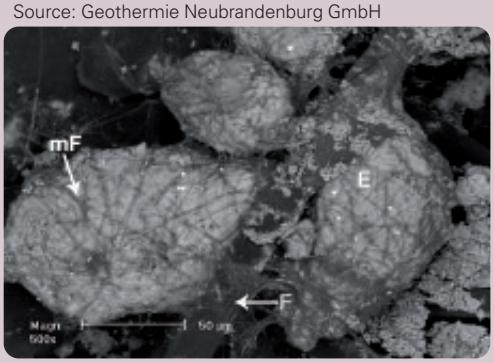


Abb. 4: REM-Bild (BS), Eisenhydroxidklumpen (E) umwickelt mit Fäden (mF) in einem Filterbeutel (F=Filterbeutelfasern), KS RTG 18.08.2008

Source: Geothermie Neubrandenburg GmbH

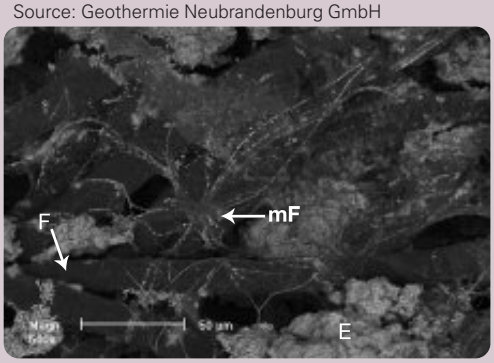


Abb. 5: REM-Bild (BS), Thiothrix-Bildungen (mF) auf Filterbeutelfasern (F) neben Eisenhydroxiden (E), KS RTG 18.08.2008

Source: Geothermie Neubrandenburg GmbH

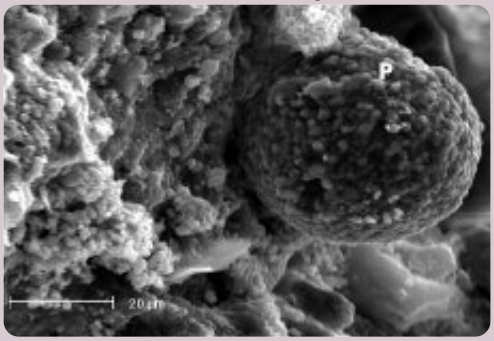


Abb. 6: REM-Bild (SE): Eisensulfidframboid (P) aus einer Sumpfprobe von KS-5 2007

The wells are equipped with a rising main, an attached pump and an injection pipe which are used in half-yearly cycles. The well heads are closed with an air-tight seal. The annular space of the wells is injected with nitrogen gas in order to prevent atmospheric oxygen from entering and to reduce the development of incrustations in the wells. The fluctuation of the nitrogen gas pressure results from the fluctuations of the groundwater level. Not only the wells but the complete storage system is charged with a pressure of 0.4 bar to 0.9 bar. The groundwater passes through pipes which above ground measure several kilometres in length and also through a number of additional parts such as heat

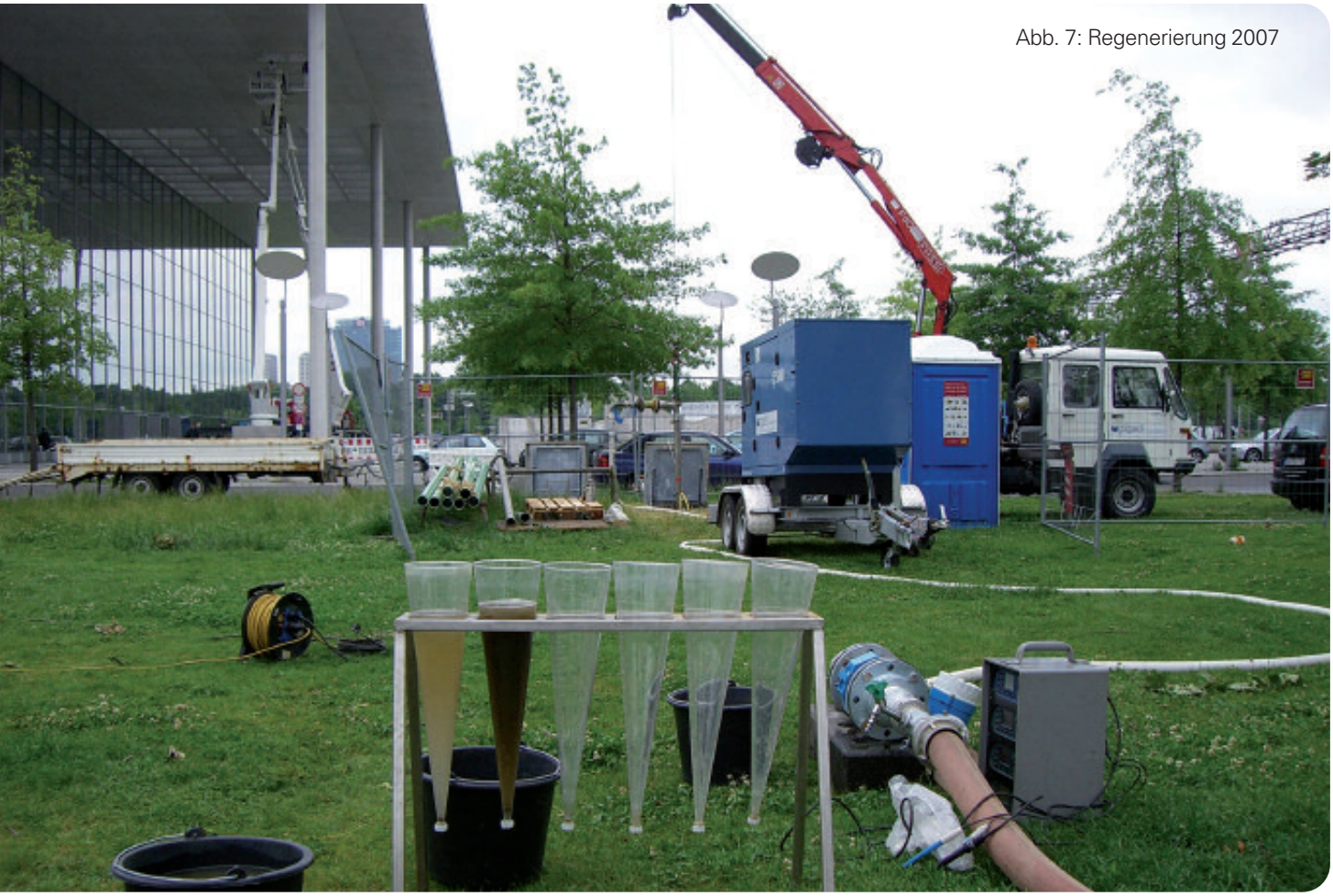


Abb. 7: Regenerierung 2007

Source: cleanwells GbR

exchangers, filters etc. These PVC pipes are not 100 percent resistant to the diffusion of oxygen which therefore can theoretically enter the system in negligible amounts.

Oxygen has been measured several times in different parts of the geothermal energy storage system to make sure that no local leakages allow the influx of oxygen to the system. The development of iron hydroxides due to penetrating oxygen is only possible to a very small degree but cannot be excluded.

Monitoring of the operation data

The geothermal wells are monitored by measuring the pressure of the complete system and recording the nitrogen pressure together with the abstraction and injection rates and the water temperature (minute values) in each well. These records including detailed information on the capacities of individual wells (which decrease over the course of the operation) are crucial for the planning of the maintenance measures.

In particular the seasonally changing injection wells are suitable for the comparison because they are all operating under the same injection pressure. Each well can be switched on and off by slide valves and the injection capacity can be estimated on the basis of the injected water quantities. The capacity can be determined even more precisely by using the nitrogen pressure which is continuously monitored for each well and can be measured very precisely as long as no additional nitrogen is fed the system.

The amount of water which can be abstracted/injected is the quotient of the respective abstraction/injection rate, and the difference of the nitrogen pressure p0 (all wells out of operation) and the pressure at the respective operation stage. The pressure difference can also be indicated by the height of the drawdown **(Fig. 3)**.

In addition to the continuously recorded hydraulic data the lifetime of the filters is also documented. If the lifetime of the filters is observed to decrease during the operation, this can be an indicator of potential problems with the operation of the system. Macroscopic and microscopic analysis of the filters can reveal the cause for the reduction of the filter lifetime. An increase in the power consumption of the pumps used for the abstraction of groundwater also signalises a fall of productivity. Furthermore redox is continually measured which enables the detection of any sudden leakages in the system.

Geochemical monitoring

Regular analysis of the water in the system has been carried out since the beginning of the operation. In 2005 the monitoring suite was extended to include both the microbiological

Tabelle 1: Wasserzusammensetzung der Grundwässer vom Kältespeicher (verschiedene Analysen von 2007, relevante Proben entnommen bei der Regenerierung von Kältespeicherbrunnen)

Datum	05.03.	04.04.	03.06	10.07
Ionen	mg/l	mg/l	mg/l	mg/l
K^+	11,4	10,9	8,9	11,7
Na^+	61,9	42,1	34,6	48,6
Ca^{2+}	121,0	133,0	93,9	140,0
Mg^{2+}	12,6	12,4	9,0	13,3
Fe^{2+}	1,83	2,0	1,82	0,7
Mn^{2+}	0,4	n.b.	0,3	0,4
Cl^-	68,5	57,0	59,0	59,0
SO_4^{2-}	198,8	192,0	65,2	170,0
NO_3^-	n.n.	n.n.	n.n.	0,1
PO_4^{3-}	n.n.	n.b.	< 0,2	1,3
SiO_2 (*SiO_3^{2-})	17,8	n.b.	15,9*	15,9
HCO^{3-}	242,0	n.b.	218,0	234,0
Gesamtmin. (g/l)	0,765	n.b.	0,51	
pH	7,23	7,4	7,38	7,24
Leitfähigkeit (µS/cm)	920	930	820	879
Redoxpotenzial (mV)	134	110	131	340

Source: Geothermie Neubrandenburg GmbH

activities and the particle loads within the scope of AquiScreen. This programme, sponsored by the Federal Ministry of Environment (BMU) aims to develop an economical fast processing monitoring software for the evaluation of microbiological influence on the operational reliability of geothermal systems. It identifies the relevant parameters which may effect the reliability in eight different monitoring locations.

Regular sampling has always taken place in the filter bowl „one" of the PLH because the energy out-storage flows through it and the filter bowls are in operation all year round. At the same time additional samples have also been taken in the filter bowls of the RTG. The filter bags of both buildings have been changed and analysed at regular intervals every five months.

As the sampled water in the filter bowls is a mixture of water from all the wells and is on the operational side of the system, the individual wells are controlled by collecting samples from these wells too. They show differences in both the quantity of solids and their chemical consistency. Further samples have been taken during well rehabilitations in the respective sumps together with samples of incrustations on pumps and pipes (injection and extraction strings). The rising mains of the injection strings have normally been covered by iron hydroxides whereas the abstraction mains have always stayed incrustation-free.

The samples of the solids have been examined under both reflected-light and scanning electron microscopes (REM/SEM). Under the latter also the percentage composition of the elements has been determined by energy dispersive x-ray spectroscopy (EDX/EDS) which provides information on the included mineral phases.

As well as the incrustations of mineral phases (iron hydroxides, iron and non-ferrous metal sulphides, carbonates and sulphur), particles from the aquifer (detrital quartz, clay minerals) and a few particles from the construction (e. g. filter gravel) can be differentiated in the sample material. Since the very beginning of the operation the mineral phases mainly consist of iron hydroxides which build up a thick crust. Approx. ten percent of the incrustations are calcium carbonates found in combination with iron hydroxides. Their proportion varies a little according to the seasons and depending on the differences of the groundwater temperature. Iron sulphides which were detected during long filter lifetimes in 2001 represented only a very small proportion of the incrustations. As of 2007 more sulphides were found, relatively often within and underneath iron hydroxide incrustations. Also iron framboids were identified in the samples from the well sumps.

The sand originating from the aquifer found in the filter bags was high up to 2007 exceeding 20 percent of the total amount. Its percentage decreased to five percent after the rehabilitation of the majority of the wells during the spring 2007. Nearly 85 percent of the solids were very fine-grained iron hydroxides with a particle size of 5 µm and iron hydroxide particles larger than this were rare from the summer of 2008.

Regular water samples together with those for the microbiological examinations have also been taken to allow early detection of possible causes of changes in the system. The composition of the groundwater at the Reichstag has been documented in **Table 1**. Between 1998 and 2008 the calcium content varied from 90 mg/l to 140 mg/l, sulphates from 65 mg/l to 200 mg/l, the total mineralization from 0.5 mg/l to 0.7 g/l, the DOC content from 2.7 mg/l to 8.5 mg/l and sodium from 34 mg/l to 62 mg/l. The pH value was slightly basic at 7.38. Variations in the groundwater composition corresponded with changes to the system's operating mode.

Microbiological monitoring and solid loads

Between August and October 2008 the filter lifetimes decreased from the normal length of > 2,000 h to less than 100 h and the solid load of 5 mg/m³ increased to 22 mg/m³ with a mesh size of 25 m. Particle quantities and compositions of the flow being delivered to them were extremely different in all the five wells of the southern field.

The portion of the solids > 0.45 µm ranged from 0.2 g per m³ water in the wells KS-8 and KS-10 up to 6.2 g m³ in the well KS-2. Mostly fine-grained iron hydroxides (60 percent)

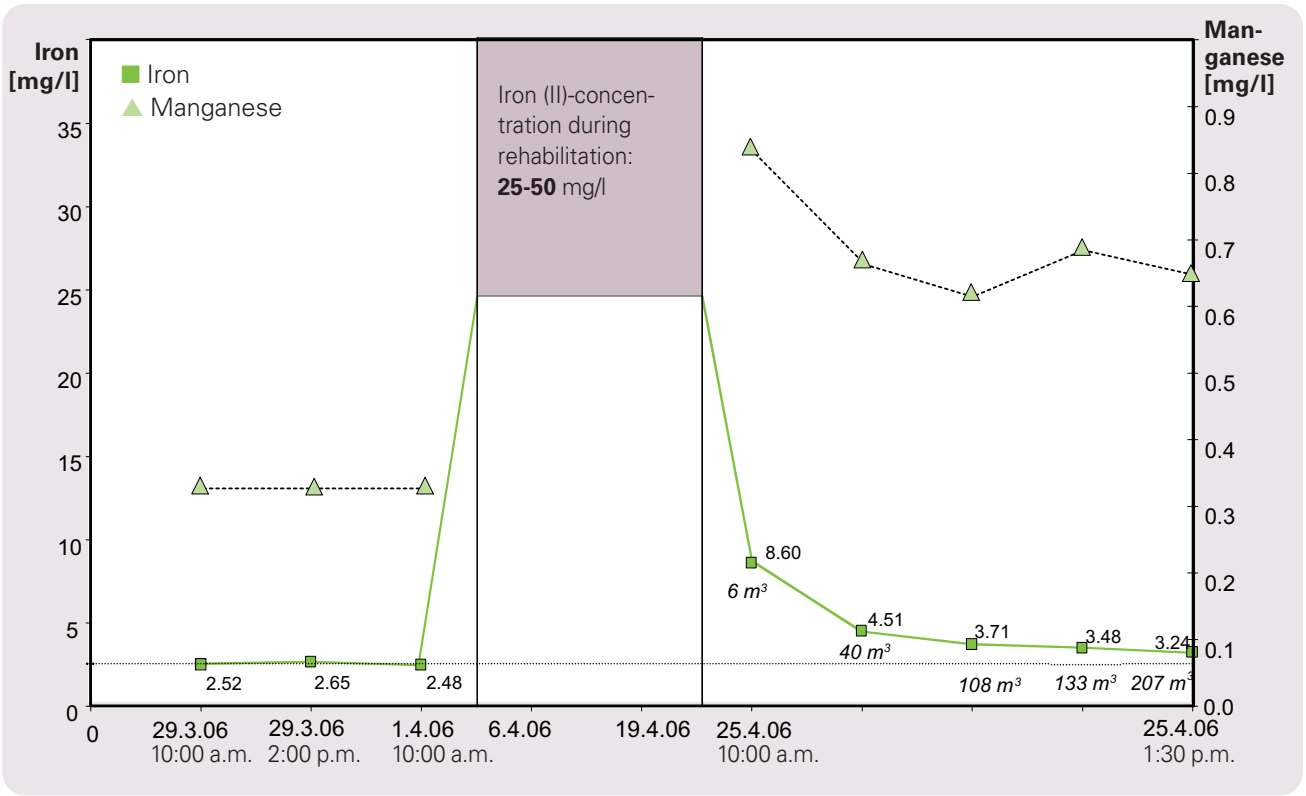


Abb. 8: Verlauf der Eisen- und Mangangehalte während der Regenerierung der KS-3 2006

were discovered in the KS-2, whereas increased amounts of sulphides (60 percent) were found in the KS-8 and the KS-10. The clay-silt portion (instead of detrital sand) was approx. 20 percent in all wells. It was striking that the wells with high solid loads also contained a lot of iron hydroxides.

At the same time small quantities of solids in the examined filter bags caused remarkable pressure differences as well. Instead of 200 g a filter bag could only absorb 20 g. The discovered solids were far finer grained than normal with particle sizes around 5 µm and mainly consisted of red-brown iron hydroxides. In addition larger round „iron hydroxide lumps" were often found wrapped with thin, loose fibres **(Fig. 4)** which in turn contained approx. 1 µm high density thick beads (Fig. 4). According to microbiological examinations by the project partners at GFZ German Research Centre for Geosciences in Potsdam the fibres originated from bacteria called Thiothrix **(Fig. 5)**. These bacteria were responsible for slime development in the filter bags and the massive reduction of their capacity.

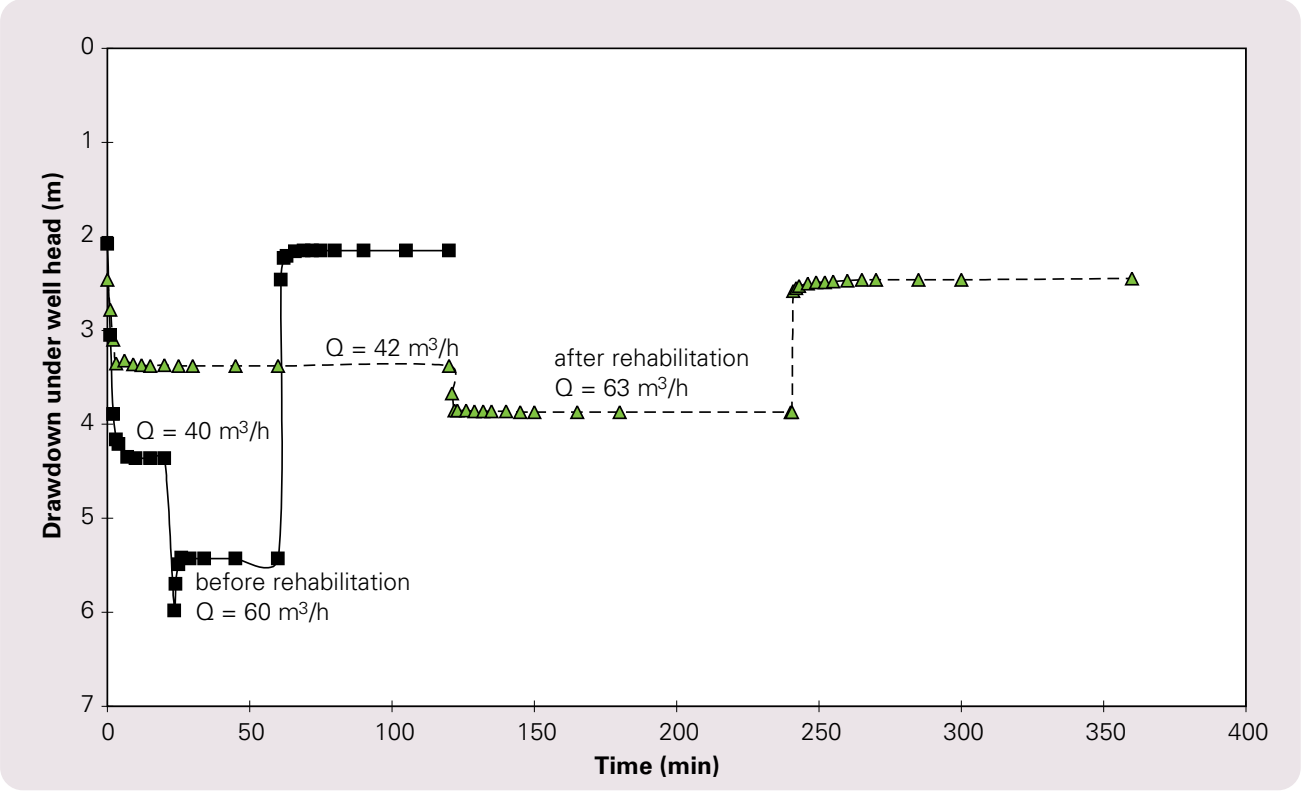
Spiral formations approx. 20 µm in length together with straight iron hydroxide pipes of 10 µm in length and 2 µm in diameter were also found in the filter bags. Organic fibres and films covered the felt of the filters which clogged their pores. Later in September the iron hydroxide clumps often also contained single oval iron sulphide flakes approx. 1 µm in size. Their appearance had never been observed before. Furthermore, single iron framboids were detected in the samples from the well sump originating from a microbiological growth **(Fig. 6)**.

A disinfection programme of all the wells and system components of the geothermal system in November 2008 brought back the normal filter life times and since then they have even exceeded the 2,000 h. The solid load also reduced back to 0.02 mg/m³ with a mesh size of 25 µm in the course of the operation, indicating that microbiological processes have a great influence on the development of solids.

Mechanical cleaning and hydraulic rehabilitation of the wells

The detailed data recorded during the systematic monitoring enables a prognostic and an individually planned maintenance strategy to be developed for each well. The rehabilitation of wells is carried out in regular intervals, however, some wells require additional maintenance measures. The first rehabilitation exercise, excluding the wells KS-11 and the KS-13, took place in 2002. The well KS-3 had to be rehabilitated again in 2006, a further eight wells had to be rehabilitated in 2007 and the wells KS-1 and the KS-9 were rehabilitated in 2009 **(Fig. 7)**.

The wells have a depth of 60 m and they have been lined with PVC casing. In their lower part the most productive zone of the aquifer in each has been tapped by placing the response zone there. This was constructed with a continuous-slotted screen (slot size 0.5 mm) of stainless steel surrounded by a gravel pack (grain size 0.71 mm to 1.25 mm). Depending on the season a maximum amount of 60 m³/h is injected / abstracted at varying rates. A number of different mechanical and hydraulic methods of rehabilitation



Source: Geothermie Neubrandenburg GmbH

Abb. 9: Pumpversuche der Bohrung KS-9 (2008) vor und nach der Regenerierung des Brunnens

have been applied and their efficiency with respect to the injection capacity / productivity has been tested and analysed in detail over the past ten years.

The following rehabilitation methods have been applied to date:

- Mechanical rehabilitation with well brushes and intense pumping (2002, 2006, 2007, 2008)
- Hydraulic rehabilitation with jetting (2002, 2006)
- Chemical rehabilitation with gravel washer, i. e. multi-chamber equipment (2007, 2008)
- Hydromechanical rehabilitation with pressure impulses (2007, 2008)
- Chemical rehabilitation by pressure impulses (2007, 2008)

Firstly the multilayered iron hydroxide incrustations have been loosened by brushing the wells and pumping them out with submersible pumps. A subsequent hydraulic rehabilitation of the gravel pack and the adjacent geological strata by means of jetting or pressure impulses has then improved the performance of the well considerably. The method of jetting has only been applied along the screen in intervals of 3 m with a working pressure between 160 and 250 bar. During the simultaneous pumping out of the section under treatment, the quantity of solids has been controlled continuously. The method of pressure impulses has also been used for both the hydromechanical and chemical rehabilitations. The screen was treated in sections of 0.5 m by an impulse generator creating three impulses of a gas mixture in intervals of 40 seconds.

Chemical rehabilitation

Despite the limited oxygen in the wells clogging with iron hydroxides takes place continually. In addition a partial sanding and a growth of temporary mucous obstructions have also been observed in them. Three major groups of particles have been identified in the flow delivered from the wells and in the system components above ground:

(1) Sand particles, plastic and GRP fibres originating from the filters can be found in the filter bags together with random rust particles. These particles represent with less than 1 percent a negligible portion of the total amount.

(2) Detrital particles are transferred from the aquifer through the gravel pack and the screen due to the strongly varying abstraction / injection rates. This accounts for approx. 20 percent.

(3) The majority of the recorded particles consists of iron hydroxides and sulphides which grow in the thermal storage plant representing approx. 80 to 85 percent of all the identified particles. The percentage of the sulphides, mainly iron sulphides including an increasing amount of copper sulphides, is with five percent rather small. Carbonates (calcite, aragonite) amount up to ten percent.

In line with the mineralogical content of the analysed well incrustations a pH-neutral reducing agent suitable for the dissolution of iron and manganese hydroxides is used for

Abb. 10: Filter von KS-1 vor Regenerierung 2008

Source: H. Anger's Söhne Bohr- und Brunnenbaugesellschaft mbH

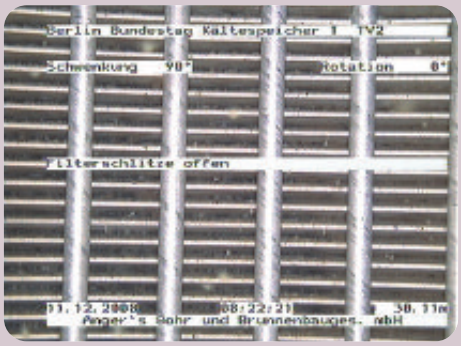
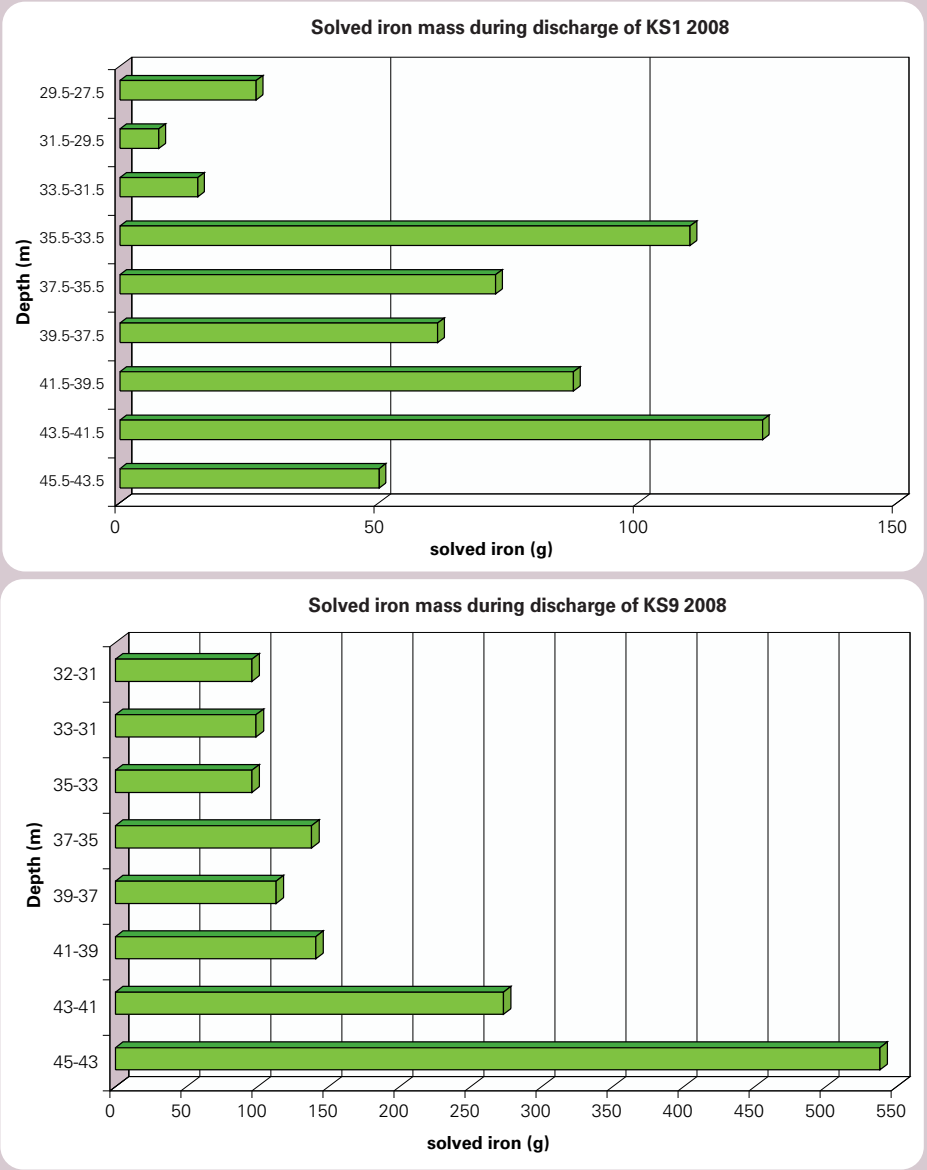


Abb. 11: Filter von KS-1 nach Regenerierung 2008

Source: H. Anger's Söhne Bohr- und Brunnenbaugesellschaft mbH



Source: Geothermie Neubrandenburg GmbH

Abb. 12: Entferntes Eisen(II) aus der Bohrung KS-9 und KS-1 in Folge der Einwirkung des eingesetzten pH-neutralen Reduktionsmittels

the chemical rehabilitation. The agent is first mixed with water and then injected in the section of screen to be treated. The chemical reaction takes place in 45 minutes during which the working solution is circulated in the treatment area. The subsequent clear pumping is continued until the reaction products have been removed and the initial groundwater values have been restored.

The working solution is a strong reducing agent containing sodium salts which are transformed into chemically and microbiologically harmless reaction products during the reaction time. It causes an increase in the specific electrical conductivity and the sulphite concentration as well as exceptionally high iron (II) values in the groundwater due to the dissolution effects. The pH value hardly changes [6]. These four parameters are monitored with measuring probes and control strips during the discharge of the used working solution. The sand content and the turbidity are also recorded.

The iron and manganese content during a rehabilitation programme are described in **Figure 8**. The concentration of iron (II) in water increases significantly due to the efficiency of the reducing agent. The total quantity removed from the well can easily be calculated by continuously measuring the iron (II) concentration, the pumping rate and the length of time during which abstraction of the fluid takes place after the reaction time which varies a lot between the individual wells. In the areas of the aquifer which are finer grained in particular more iron (II) is mobilized due to larger quantities of iron hydroxides and sulphides located near the borehole wall before the well rehabilitation.

Determination of well capacity and verification of results

The exact determination of the capacity of the individual wells is only possible to a limited extent due to the simultaneous operation of a number of them. There is also a great difference between their yields ranging

The results of the different rehabilitation methods have proved that only a combined hydraulic-chemical treatment can secure the well operation in the long term.

from 30 to 90 m³/h/m because of the geological heterogeneity. The respective pump tests have shown however that the primary capacities of the wells have been reduced to 40 percent before the rehabilitation programme took place.

The results of the pump tests before and after the rehabilitation programme in well KS-9 in 2008 have been documented in **Figure 9**. The drawdown of 3.4 m before the rehabilitation decreased to 1.9 m after the treatment which means that the productivity of the well nearly doubled from 17.6 m³/h/m to 33.1 m³/h/m.

The efficiency of the hydraulic rehabilitation programme and possible damages caused by the treatment have been documented by CCTV camera inspections **(Fig. 10 and 11)**. All wells have also been measured with a focussed gamma log. The intensity of the gamma rays was strongly influenced by clay and feldspar next to the borehole wall. Pure quartz sands showed low gamma intensities between 15 and 40 API. Though the natural gamma radiation in the area adjacent to the borehole wall was dampened by the continuous slot screens, the values next to the screens were generally higher before the rehabilitation than they were after it. The differences were particularly remarkable in areas of silty sands. Consequently it was assumed that a transfer of clay particles has taken place within the aquifer around the borehole due to the operation of the geothermal system, which has then been removed by the hydraulic rehabilitation. The examination of the solids also confirmed the relevancy of clay particles which accounted for 20 percent of the total amount of solids.

During the chemical rehabilitations of the wells KS-1 and KS-9 two different quantities of the rehabilitation agent were applied in 2008. The dosage for the KS-9 was 150 kg while the KS-1 was treated with 75 kg only. These amounts correlated with the amount of dissolved iron (II) in the used working solution including the reaction products, i. e. they were much higher in the KS-9 than in the KS-1 **(Fig. 12)**.

Summary

The uninterrupted stability of the production/injection capacities of the geothermal wells is based on timely rehabilitation programmes and the applied technical measures for avoiding iron-hydroxide precipitation. The results of the different rehabilitation methods have proved that only a combined hydraulic-chemical treatment can secure the well operation in the long term. Although a chemical well rehabilitation programme always requires more time, cost and technical complexity, both the increase of the well capacity and the sustainability of the final outcome more than justify the costs.

The method of pressure impulses achieved particularly good results during the hydraulic rehabilitations of the wells. The well KS-6 was tested before rehabilitation, after the hydraulic and again after the chemical treatment in 2006. The pressure impulses improved the well's ability to inject water by 50 percent which was doubled by the chemical rehabilitation with the pH-neutral reducing solution. A total amount of 1.5 kg iron (II), i. e. 2.4 kg of iron hydroxide was removed out of the well KS-9 together with 200 kg solids during the rehabilitation in November 2008.

The systematic monitoring of the geochemical and microbiological data has not only secured the functionality of the complete air-conditioning system of the parliament buildings during the past ten years, but also provided for the development of a well-timed maintenance strategy according to the individual characteristics of each well.

Above all it has enabled the identification and the elimination of possible interruptions to the system in advance. These would otherwise have developed unnoticed during the routine operation of the system until the problem occurred and caused a breakdown.

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