Hydraulic stimulation of a sedimentary geothermal reservoir in the North German basin: case study Groß Schönebeck

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Abstract

In 2000, the former Groß Schönebeck gas exploration well was reopened and deepened to 4294 m depth to serve as a geothermal in-situ laboratory for testing stimulation concepts. The objective of these stimulation operations is to create secondary flow paths and to improve the inflow performance of the well. The generation of geothermal electricity from sedimentary reservoir rocks of the North German Basin is the final goal of these investigations.

Proppant-gel-frac techniques as well as waterfrac techniques were used in several different experiments. During the proppant-gel-frac, two intervals of Rotliegendes sandstones were hydraulically stimulated in January 2002. The intervals were sealed using a mechanical packer at the top and by a sand plug at the lower end. High-viscosity fluid with proppant was employed for stimulation. Flow rates were increased significantly, and a fracture with a vertical length of 150 m was generated due to this operation. However, the observed productivity was insufficient for power production. Further stimulation of the reservoir rocks in this well was performed in two experiments in winter and fall 2003 using the waterfrac technique. More than 15 000 m^3 water was injected in different pressure steps with flow rates up to 80 $l\ s^{-1}$. Reservoir properties associated with mechanical reactions were observed at injection flow rates above 9 $l\ s^{-1}$. Recent production test data show a productivity index of 14 $m^3\ h^{-1}\ MPa^{-1}$. This productivity index seems to be sufficient for geothermal power production.

It is intended to use this well as an injection well in a doublet system.

[Stimulation eines sedimentären geothermischen Reservoirs im Norddeutschen Becken: Fallstudie Groß Schönebeck]

Kurzfassung

Die Ergebnisse der seit 2002 in der Bohrung Groß Schönebeck durchgeführten Stimulationsexperimente zeigen eine stetig steigende Erfolgskurve in Bezug auf die erzielte Produktivität. Die Methode des massiven Wasserfracs ergänzt durch eine abschließende Stützmittelbehandlung erweist sich damit als Schlüsselverfahren zur Steigerung der Produktivität sedimentärer geothermischer Reservoire. Ein weiterer wichtiger Meilenstein auf dem Weg der geothermischen Technologieentwicklung ist damit erreicht.

Hinzu kommt, dass die hier erfolgreich getestete Technologie weltweit auf Gebiete ähnlicher geologischer Struktur übertragen werden kann, da Deutschland aufgrund seines für Mitteleuropa typischen geologischen Untergrundes repräsentativ ist.

Nach den erfolgreichen Tests liegt ein Verfahren vor, mit dem die Produktivität einer niedrigthermalen sedimentären Lagerstätte kontrolliert gesteigert werden kann. Die nächsten Ziele sind das Abteufen einer zweiten Bohrung und die Durchführung des Kommunikationsexperimentes. Das Konzept einer späteren geothermischen Nutzung sieht vor, dass die aus der Förderbohrung geförderten Tiefenwässer nach ihrer thermischen Nutzung über die Injektionsbohrung wieder in den Speicher eingeleitet werden.

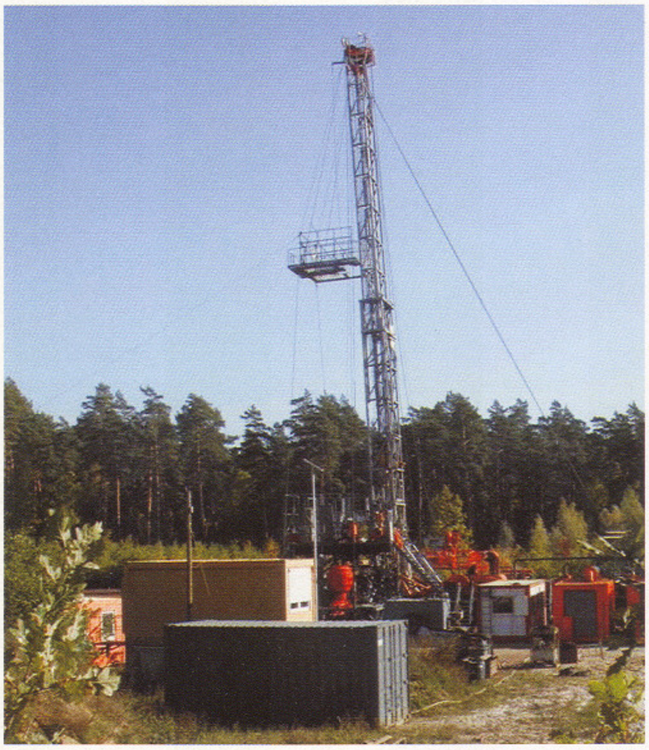

Figure 1:
Workover rig, Groß Schönebeck well, October 2003.

Abbildung 1:
Bohranlage für die Aufwältigung der Bohrung in Groß Schönebeck, Oktober 2003.

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Introduction

Sustainable and environmentally-friendly energy can be generated from the conversion of the Earth's heat (from formation fluids) into electricity. Production of deep thermal water with flow rates of about 50 m³ h⁻¹ is a precondition for the economic generation of electricity (KÖHLER & SAADAT 2003). Technology to stimulate geothermal reservoirs can be summarised as Enhanced Geothermal Systems (EGS), which offer ways to improve the potential of geothermal power generation and are characterised by reservoir temperatures above 100 °C.

The required temperature for this purpose can be found in the North German Basin at depths of 4000 m to 5000 m. However, the permeability of the rocks at this depth is generally insufficient for the necessary flow rates.

The Groß Schönebeck site is promising. The well makes deep hydrothermal aquifers accessible with formation fluids of 150 °C at bottom hole, and porosities of up to 10 % (HUENGES & HURTER 2002). Experiments in this in-situ geothermal laboratory should lead to the development of reliable technology for sufficient production of deep fluids in such reservoirs.

Geology

The drill site is located northeast of Berlin. The well penetrates the typical sequence of North German Basin geological formations. A 2 370 m series of Quaternary to Triassic sediments is underlain by 1 492 m of Zechstein evaporites and the section of this well, which was foreseen for testing, which comprises 400 m of Rotliegendes Formation (siltstones, sandstones, conglomerates, and 60 m of underlying volcanic rocks) down to the total depth of 4 294 m (HUENGES et al. 2002).

Technology Development

Technologies have to be developed to enhance the existing flow. This can be summarised by the term *hydraulic fracturing*. During stimulation experiments, fluids under high pressure penetrate the rock and generate cracks or extend existing fractures. These procedures are commonly used in the hydrocarbon industry (ECONOMIDES & NOLTE 1989) as well as in Hot Dry Rock (HDR) technology (HETTKAMP et al. 2004). However, the objective of using hydrothermal reservoirs requires a special stimulation technique to be able to produce considerably higher amounts of fluids compared to hydrocarbon reservoirs. In contrast to HDR technology, our aim was not to install a heat exchanger but to get access to formation fluids in the reservoir. The most important parameters in these experiments include fracture fluid volume, injection rate, viscosity (water with added polymers), composition (chemical variants or added proppants) and the selection of the depth interval to initiate new fractures.

Stimulation experiments

Sandstone stimulation

Stimulation of the Rotliegendes took place in January/February 2002. Several experiments were made using proppant-gel-frac techniques in two intervals of the Rotliegendes sandstones. Experiment design comprised the isolation of the bottom boundary of the interval of interest by filling the bottom of the well with sand. The top of the interval was sealed with a mechanical packer. High viscosity fluid (linear gel) with proppant was employed for the stimulation (LEGATH et al. 2003). Flow rates were increased significantly and a fracture with a vertical length of 150 m was generated by this operation

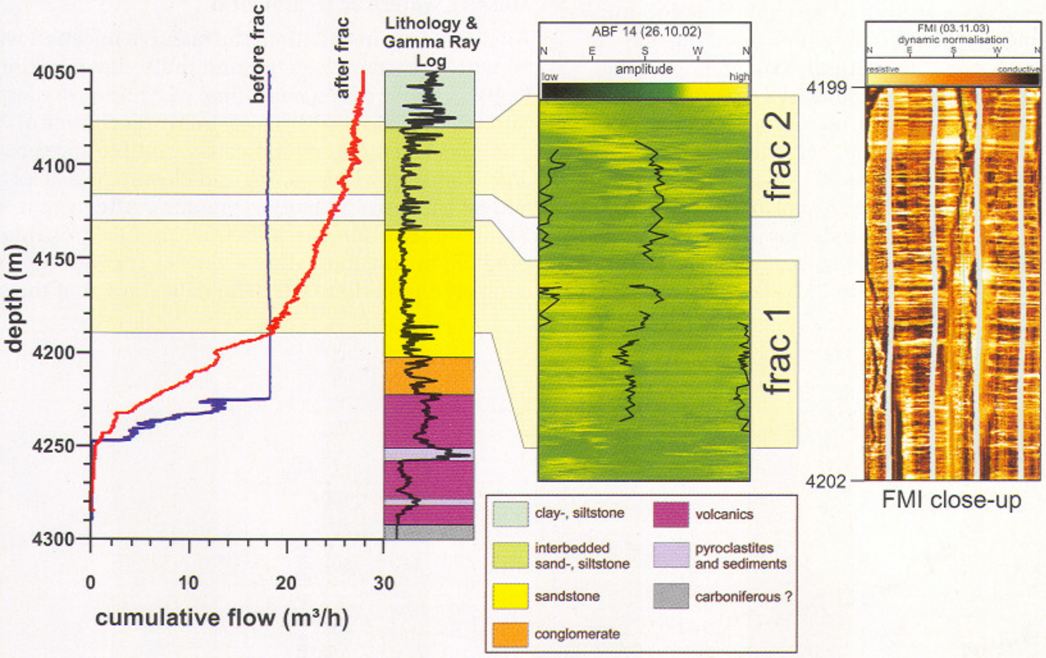

Figure 2:
Stratigraphy and lithology of the hydraulically fractured sections in the open-hole interval including a comparison of flowmeter logs (first productivity index PI = 1.1 m³ h⁻¹ MPa⁻¹ and second production test PI: 2.2 m³ h⁻¹ MPa⁻¹). The Borehole Televiewer (BHTV) and Formation Micro Imager (FMI) images illustrate the open fractures parallel to the maximum horizontal compressive stress (SH).

Abbildung 2:
Stratigraphie und Lithologie der Sektion des offenen Bohrlochintervalls in denen hydraulische Risse erzeugt wurden sowie ein Vergleich der Zuflussmengenmessungen (erster Produktivitäts-Index PI = 1.1 m³ h⁻¹ MPa⁻¹, zweiter PI = 2.2 m³ h⁻¹ MPa⁻¹). Die Borehole Televiwer (BHTV)- und Formation Micro Imager (FMI)-Bilder illustrieren die offenen Risse parallel zur maximalen horizontalen Hauptspannung (SH).

(see fig. 2) (Holl et al. 2003; Holl et al. 2004; Zimmermann et al. 2003). However, the observed flow rates were not sufficient for economic power production. Legath et al. (2003) conclude that the experimental results were strongly influenced by the proppant properties during the treatment. Another parameter to improve the results in a forthcoming experiment is the volume of injected frac fluid. Therefore, the experiments were continued with a procedure for injecting volumes at least two orders higher into the reservoir.

Massive waterfrac treatment I

In January/February 2003, the borehole section was still without a casing between 3850 m and the total depth of 4294 m.

At the beginning of the waterfrac treatment, low rate injection tests were performed to use the injection behaviour to characterise the reservoir properties. Flow rates between 1 and 6 l/s were applied. The hydraulic parameter of the reservoir and the fracture could be derived from analysis of the shut in periods (Tischner et al. 2003, Zenner et al. 2004). The hydraulic responses are characterised by a pronounced bilinear flow regime, while the pseudo-radial flow regime is never reached. The bilinear flow period is a strong hydraulic indication for the existence of a vertical fracture in the well. The analysis of the response data reveals a fracture conductivity slightly increasing with increasing injection rate. An increase in injectivity is observed at increasing rate/pressure corresponding to the pressure-dependant fracture conductivity. All low rate injection tests could be modeled consistently using a unique value for the matrix transmissibility of about T = 3–4 × 10^{-14} m^3, which is smaller by 1 to 2 orders of magnitude in comparison to values deduced from laboratory core measurements of the Rotliegendes sandstone layer. The pronounced discrepancy between laboratory and field measurements can be explained by spatially extensive formation damage.

In a second step, a massive water frac was conducted to propagate artificially induced fractures in the reservoir and to find hydraulic connections to natural fractures or other permeable structures. Flow rates up to 24 l s^{-1} were injected. A very gentle rise in pressure with increasing injection rate was observed at injection rates higher than 9 l s^{-1}. This behaviour indicates a fracturing process.

However, the massive water frac could not be performed as planned. Observed borehole breakouts periodically led to hydraulic restrictions in the wellbore resulting in an unusually high wellhead pressure up to 250 bar. As a result of this problem, flow rates higher than 24 l s^{-1} could not be realised and the duration of the test had to be shortened. The borehole breakouts mainly occurred close to the casing shoe at about 3 900 m. Despite these restrictions, a free flowing well test after the waterfrac provided good results. 250 m^3 water were produced within 5 hours at an average rate of 11 l s^{-1}. Compared to the low rate injection tests before, and compared to the results after the sandstone treatment, a significant increase in productivity was obtained (see fig. 3).

The results of the production test further supported continuation of the waterfrac treatment with higher rates after stabilising the wellbore.

Reopening, deepening, and liner installation in the well

In October 2003, the well was re-opened and deepened to 4 309 m, and an additional liner was installed from 3 850 m down to the final depth to stabilise the well. Prior to the liner installation, an extensive logging programme was performed to acquire information about the geological structure and the lithology of the borehole section of interest. Formation Micro Imaging (FMI) measurements, forming a micro-resistivity image of the borehole wall, very clearly show the produced vertical fracture of 150 m length which was first observed by BoreHole Televiewer (BHTV) measurements after the sandstone frac treatment (see fig. 2). The observed vertical fracture is oriented parallel to the maximum horizontal stress, which has a nearly N–S orientation (18.5° +/- 3.7°) (Holl et al., 2004). The liner was installed in the lower part below 4 135 m installation depth with perforated tubes (diameter of holes 15 mm, 93 holes per metre, circumferential) to ensure hydraulic contact to the formation. In this stabilised well, the massive water frac experiment was continued into autumn 2003.

Massive waterfrac treatment II

After the liner installation, the massive injection was continued with a pressure step test and multi-day injection of 30 l s^{-1} to 40 l s^{-1}, and over a short time of 2 minutes, of up to 80 l s^{-1} into the open hole with a total injection volume of 7 291 m^3.

The pressure step test indicates multiple fracture generation and extension with opening and closure pressures between 60 and 88 bar above formation pressure. After a shut-in period of 34 hours, 859 m³ of water was produced during a 24 hour production test indicating a further increase in productivity compared to earlier tests. The data show that the stimulation

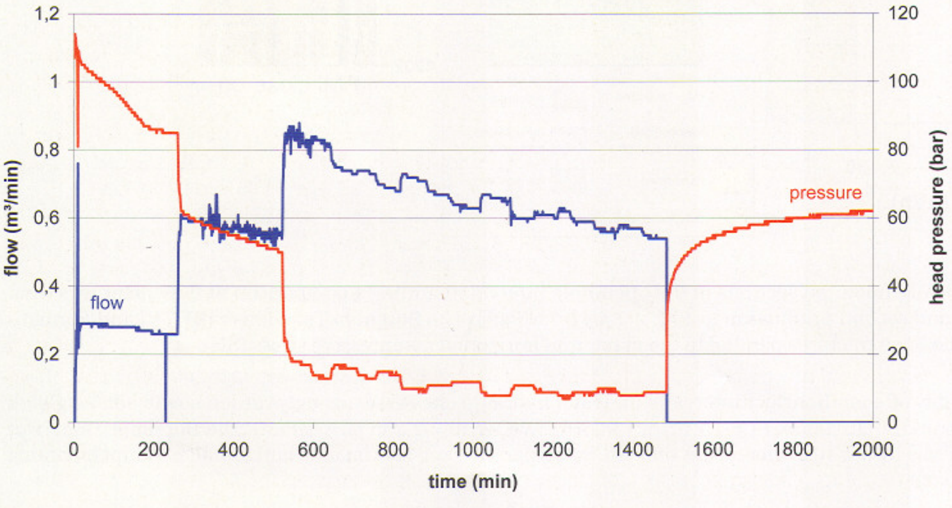

Figure 3:
Flow (blue) and well head pressure (red) during the flow back test in December 2003.

Abbildung 3:
Fließraten (blau) und Kopfdrücke (rot) während des Auslauftests im Dezember 2003.

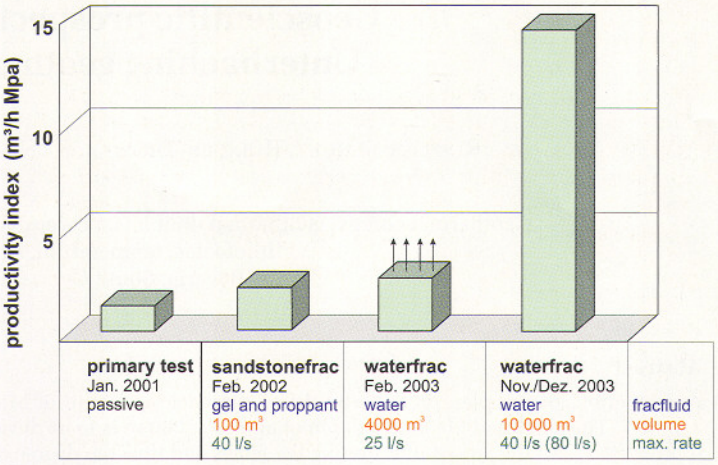

Figure 4:
Plot of enhancing productivity in Groß Schönebeck 3/90 during several reservoir treatments since 2000. The arrows at the Feb. bars indicate uncertainties due to an obstruction in the well. The values at the Nov./Dec. bars reflect productivity after the fractures had closed.

Abbildung 4:
Produktivitätsentwicklung der Bohrung Groß Schönebeck 3/90 nach mehreren Reservoirbehandlungen seit 2000. Die Pfeile and den Feb. Balken weisen auf Unsicherheiten in der Bestimmbarkeit der Produktivität auf Grund einer Obstruktion in der Bohrung hin. Die Werte an den Nov./Dez. Balken stellen die Produktivität nach der Rissschließung dar.

treatments yielded an increase of productivity with up to $14\ m^3\ h^{-1}\ MPa^{-1}$ determined at fracture closure pressure (fig. 3). This closure pressure was indicated by the change of slope of the pressure decline curve, which started from values above the fracture closure pressure. From this it follows that there was no self propping (shear displacement of fracture faces, BRISTER & LAMMONS 2000) of the fracture in the sandstones.

Conclusions

The results reflect the learning curve from several reservoir treatments (fig. 4). These experiments mark major steps towards developing a procedure to increase the thermal water productivity from a previously low permeability sedimentary reservoir. Generally, a sole waterfrac treatment cannot be assumed to result in stable long term behaviour. Therefore, for "engineering" the reservoir, we recommend massive waterfracs with a proppant treatment at the end to ensure the creation of a long term conductive fracture.

The productivity values obtained seem to show the feasibility of geothermal power production from a sedimentary geothermal reservoir. The concept for power production from the Groß Schönebeck reservoir comprises a doublet of wells. The second well should be completed as a production well. The existing well can be used as an injection well.

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