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WELL PATH DESIGN AND STIMULATION TREATMENTS AT THE GEOTHERMAL RESEARCH WELL GTGRSK4/05 IN GROß SCHÖNEBECK

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ABSTRACT

At the geothermal research drill site at Groß Schönebeck (north-east Germany) a second well has been drilled to complete the doublet system for geothermal power production. To enhance the productivity of this well hydraulic stimulation treatments are scheduled. The aim of this paper is to present a line of argument for a decision guidance concerning the optimum design for fracture treatments in the different reservoir sections.

INTRODUCTION

The technical feasibility of geothermal power production will be demonstrated in the geothermal research wells Groß Schönebeck using a borehole doublet. This task includes safeguarding the thermal fluid cycle and the optimisation of energy conversion technology at the surface. The existing well Groß Schönebeck (E GrSk 3/90) was tested to investigate scenarios of enhancing productivity of thermal fluid recovery from the underground (Legarth et al., 2005; Reinicke et al., 2005; Zimmermann et al., 2005). The forthcoming project is to complete the doublet with a second well (Gt GrSk 4/05) with a total depth of 4400 m followed by stimulation treatments to enhance productivity. For the development of a maximum effective pay zone the new well is inclined in the reservoir section with 47° and was drilled in the direction of the minimum horizontal stress (σ_h=288°) for optimum hydraulic fracture alignment in relation to the stimulated pre-existing well E GrSk 3/90. Hence the orientation of the fractures will be 18°N in the direction of the maximum horizontal stress (Holl et al., 2005).

The fracture treatment design comprises three fracture treatments, two in a lower Permian the sandstone section (Upper Rotliegend, Dethlingen Formation) and one in the volcanic section (Lower Rotliegend). In the low permeable volcanic rocks it is intend to perform a waterfrac treatment in conjunction with a low proppant concentration to achieve a long-term productivity and a fracture half length of up to 200 m. It was shown previously from treatments in the existing well GrSk3/90 that the high permeable sandstones did not show a self propping effect. Hence it is planned to perform two gel proppant treatments in the sandstones to maintain long-term access to the reservoir.

GEOLOGICAL TARGET

The target horizon is built up of Upper Rotliegend II sandstones (Dethlingen Formation/Lower Elbe Subgroup) and Lower Rotliegend volcanic rocks. The depth of the reservoir is a consequence of the geothermal gradient in the region north of Berlin: the regional temperature of 150° in 4200 m depth TVD is the minimum requirement for power generation from geothermal heat. Geothermal doublet systems are only reasonable under this temperature characteristic with sufficient permeabilities of the reservoir rocks. The highest permeability is proofed in the clean sandstones of the Lower Dethlingen formation (Trautwein & Huenges, 2005; Huenges et al., 2006a) (Fig. 1). Additionally to this matrix permeability potentially occuring natural fractures and faults might increase the permeability of this formation. The wellpath should penetrate the Lower Rotliegend volcanic rock, crossing the Havel unit that is situated between the Dethlingen sandstones and the volcanics. The andesitic rocks of the Lower Rotliegend are characterized by a joint pattern that causes the permeability within this formation. In addition to the clastic reservoir, this fractured aquifer system may enhance and optimize the common productivity. The wellpath endpoint is within the volcanics. Both the Dethlingen sandstones and andesitic formations will be stimulated by hydraulic fracturing.

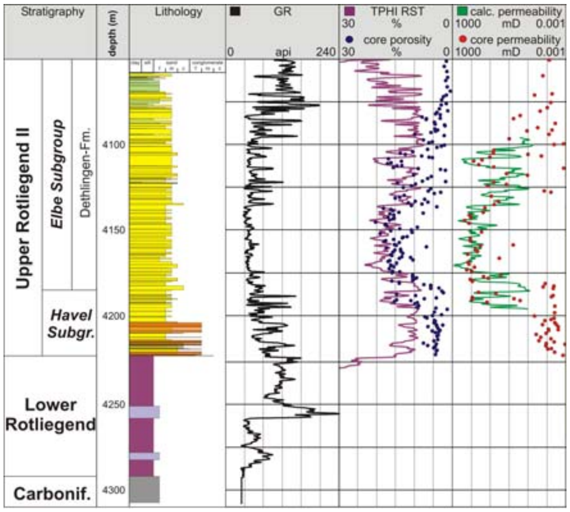

Fig. 1 Porosity and Permeability in the clastic Rotliegend (from top Dethlingen Formation) (Holl et al., 2005).

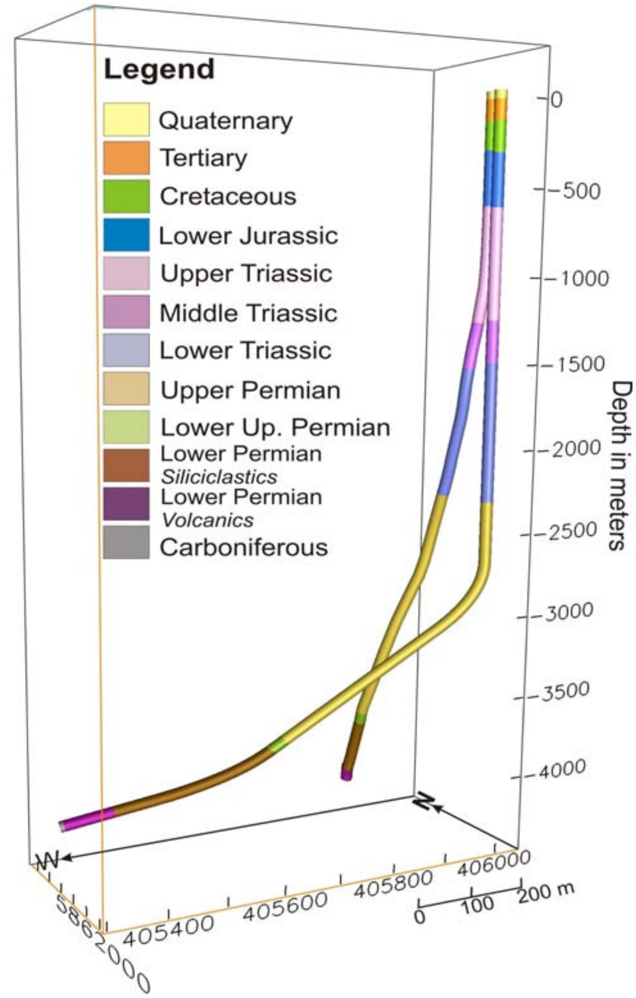

Fig. 2 3D view of the borehole profiles of the existing (behind) and the new borehole (in front) showing the geological horizons (Huenges et al., 2006b). The vertical scale (in m) is reduced by factor 0.2 compared to the horizontal scale.

WELL PATH DESIGN

The stimulation operations created secondary flow paths and improved the inflow performance of the well (Huenges et al. 2004, Zimmermann et al. 2005). After all, the situation seems favorable to go further, and drill a second well. Potential sustainable production scenarios were investigated based on coupled thermal hydraulic modeling using the geological model (Fig.1) and the parameters determined during and after the stimulation treatments. The aim was to characterize the reservoir of Groß Schönebeck 3/90 and to choose the ideal geometry for the second hole to be drilled, based on the results of the hydraulic tests (Reinicke et al., 2005; Zimmermann et al., 2005, Huenges et al., 2004), the several stimulation treatments (Legarth et al., 2005) and investigations on drill cores (Trautwein and Huenges, 2005; Norden and Förster, 2006). For modeling the coupled thermal hydraulic processes the finite element program FeFlow (Diersch, 2002) was used. Potential productivity, sustainability and the thermal behavior of the reservoir during production using a doublet system were modelled.

For the arrangement of the two wells one follows two conflicting goals. On the one hand, the wells should be located in such a way, that the pressure in the reservoir would not drop significantly during production resulting in a comparatively close distance of the wells. On the other hand, a short circuit between the wells, implying a temperature drop in the production well, should be avoided.

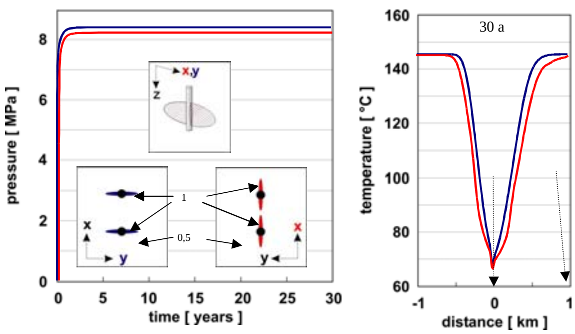

Fig. 3: Thermal hydraulic models of the thermal water loop (75 m³/h) (frac orientation parallel and perpendicular to the connecting line of both wells) with a fracture half length of 250m, respectively. Pressure vs. time within the injection well (left) and temperature distribution of a doublet with 1000m distance of injection point to production point (marked by arrows) after 30 years (right). Assumption for the fracture conductivity is 1 Dm, transmissibility of environmental rocks is 0.5 Dm.

For this, the variation of the distance between the bore holes as well as different orientations of the artificially generated fractures were examined (Fig. 3). The fracture propagation will follow the main horizontal stress direction. We investigated

- the effect of an arrangement of the fractures on the connection line of both boreholes, corresponding to the classical HotDryRock approach (red lines in Fig. 3)
- a connection line crossing the artificial fractures perpendicular to their propagation assuming a fluid flow through the natural undisturbed rocks (blue lines in Fig. 3).

At Groß Schönebeck, a reservoir with some matrix permeability, both arrangements (parallel and perpendicular) would need similar pressure respectively auxiliary energy to drive the thermal water loop (Fig. 3 left side). The risk of a temperature short circuit of the system is most probable in the parallel case (Fig. 3 right side). Both cases are connected with a minimum in using auxiliary energy but the modeling of the perpendicular case shows a thermal decoupling. Therefore this is the appropriate arrangement for a deep sedimentary reservoir with some matrix permeability. Thus, this is valid as long as no extended natural fracture systems are connected (Zimmermann et al., 2005; Legarth et al., 2005).

FRACTURE TREATMENTS AND HYDRAULIC TESTS

The general design of doublet system with expected fractures is displayed in Fig. 2. Three different fracture treatments are scheduled starting from the bottom of the well with the volcanic section. The whole well is cased and cemented with the exception of the last 20 m (perforated liner). After the first treatment at the bottom of the well this section has to be isolated by a bridge plug. Prior to the stimulation treatment a selected interval has to be perforated. The selection of this interval is due to the results of borehole measurements to obtain the best reservoir conditions.

The aim of the fracture treatments is to obtain a fracture half length of 100 - 150 m for sandstone layers and 150 - 200 m for the volcanic layer with a corresponding fracture height 80 - 100 m. The apertures of the fractures should be in the range of 5-10 mm. This will result in a total fracture volume of approx. 100 - 200 m³.

The rock mechanical and hydraulic parameters of the reservoir rocks are summarized in table 1.
The initial expected productivity index and the projected increase of productivity for the various fracture treatments are displayed in table 2.

	frac pressure	closure stress gradient	pore fluid permeability	Youngs modulus	Poisson‘s ratio	fracture toughness
volcanics	68.4 MPa	0.16 bar/m	1 mD	55 GPa	0.2	1.72 MPa m1/2
lower Dethlingen	52.2 MPa	0.125 bar/m	10 mD	55 GPa	0.18	0.59 MPa m1/2
upper Dethlingen	59.3 MPa	0.145 bar/m	10 mD	55 GPa	0.18	0.59 MPa m1/2

Table 1 Rock mechanical parameters of the reservoir rocks

	initial productivity index (PI) [m³/h MPa]	productivity index after stimulation [m³/h MPa]	FOI
volcanics	2-4	10	3-5
lower Dethlingen	6-10	30	3-5
upper Dethlingen	3-5	10	2-3

Table 2 Projected productivity indices before and after stimulation treatments for the expected reservoir rocks (FOI = initial PI /stimulated PI)

PROBLEMS IN A DEVIATED WELL

We expect convergent flow issues (in all three zones) as the additional flow through the dominant fracture will all be entering through a very small area of pipe. That is to say the fracture with a small width will intersect the wellbore at about 47 degrees meaning only one or two perforations will accept the majority of the flow. To counter this effect, it is recommended to keep the perforation intervals small while using a high shot density perforating technique. Perforations oriented to the top and bottom of the completion will allow easiest initiation of the fracture and reduce the amount of pressure drop caused in the near wellbore region. It is also recommended that to further reduce the effect of convergent flow, the slickwater treatment on the volcanics zone be ended with a high proppant concentration to increase the width in the near-wellbore region and improve inflow performance.

FRACTURE TREATMENTS IN ROTLIEGEND SANDSTONES AND VOLCANICS

Time schedule and design in volcanics

The design comprises several high flow rate intervals due to the limitation of water availability from the existing wells (approx. 50 l/s) and storage capacity in containers of approx. 1000 m³. We believe that the impact of high flow rates (150 l/s) for the fracture performance is better, even if the intervals are limited in time, compared to a constant flow rate of 50 l/s. To fill the containers, it is provided to reduce the flow rate to 20 l/s after the high flow rates. This should be far above the transition from the fracture mode to the hydraulic mode and should keep the fracture open. The number of cycles is limited for budget reasons to approximately 5 days.

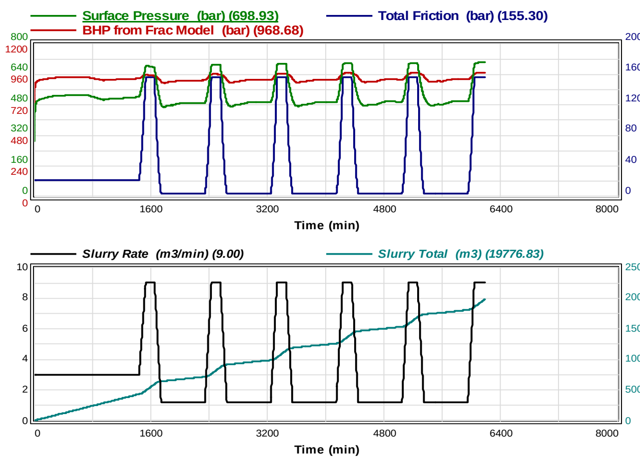

Fig. 4 Schedule and pressure development of the waterfrac treatment

The design comprises adding some abrasive agent in the fluid during the high flow rates such as sand to help etch conductivity into the fractures created and using a proppant suspending agent which gives the proppant mechanical suspension while travelling through the frac, will increase the height that will be etched and allow the proppant to travel to the end of the fracture. We consider using a friction reducing agent in the fluid as opposed to using a guar based gel.

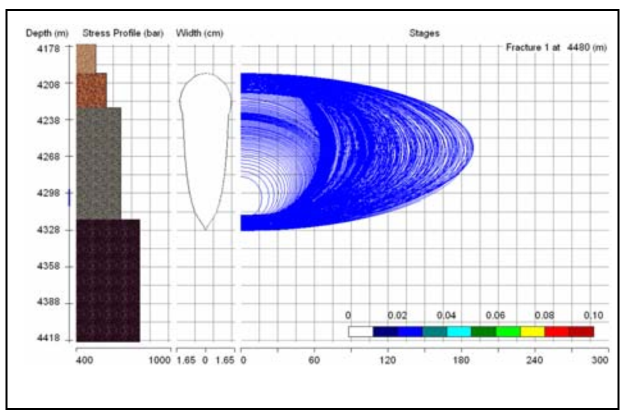

Fig. 5 Fracture dimensions from simulation in the volcanic layer

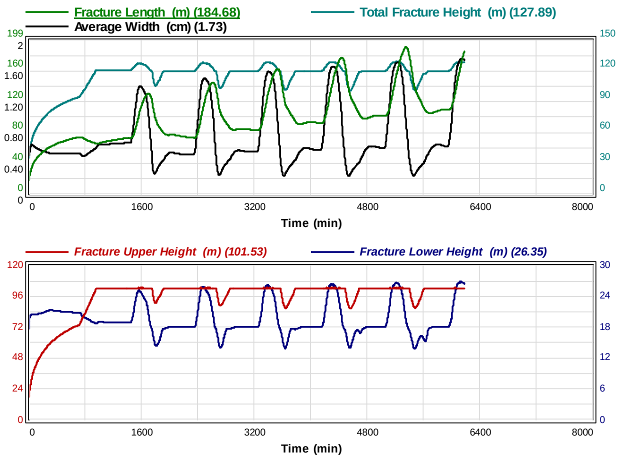

Fig. 6 Fracture geometry from simulation in the volcanic layer

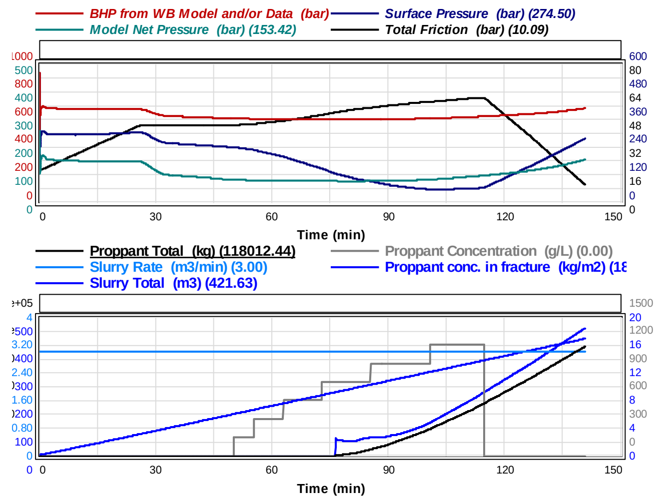

Fig. 7 Schedule of the gel-proppant treatment in the sandstone layer(Lower Dethlingen)

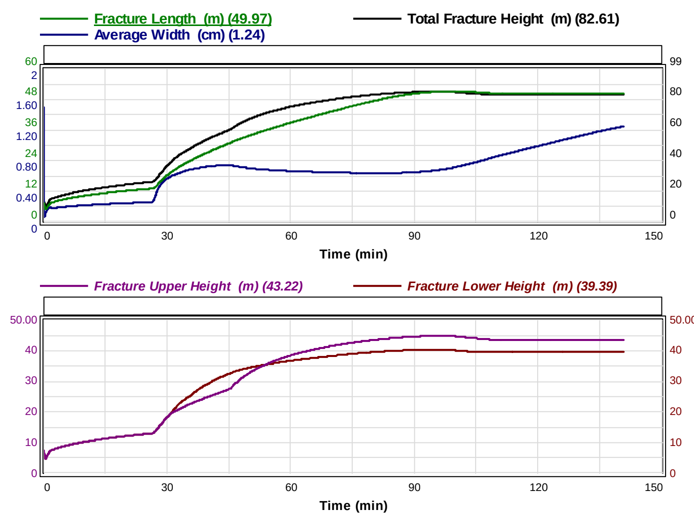

Fig. 8 Geometry of the fracture in the sandstone layer

According to simulation with FracPro (Cleary, 1994) this will lead to a fracture half length of 180 m and an average fracture width of 17 mm.

Time schedule and design in Upper and Lower Dethlingen Zones

For the treatments in the sandstone layers two different scenarios are projected depending on the initial transmissibility of the reservoir rock. This quantity is tested in advance by a casing lift test. For a transmissibility lower than 1 Dm (10^{-12} m³) a waterfrac treatment with proppant at the end (tie-back) is scheduled. For a transmissibility higher than 1 Dm a Gel-proppant frac will be performed.

We will start with a DataFRAC on the Lower Dethlingen zone to obtain information about friction and tortuosity of perforated interval. In this DataFRAC we would first pump an uncrosslinked gel which would give us an indication if any near-wellbore problems exist which could potentially adversely effect the placement of the Frac Treatment. This would then be followed by pumping 40-50 m^3 of crosslinked fluid which would give us an idea of leakoff as well as help us predict closure pressures, frac geometry and if there is any indication of pressure dependent leakoff.

The frac design is limited by the total amount of proppants, which should not exceed 120 to (due to budget limitations).

According to the simulation with FracPro this will lead to a fracture with a half length of approx. 50 m and a proppant concentration in the fracture of up to 18 kg/m² with a corresponding average fracture width of 12 mm.

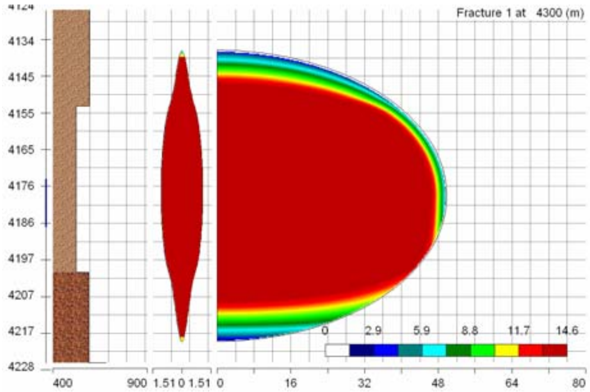

Fig. 9 Geometry and proppant concentration of the fracture in the sandstone layer. On the left the perforation interval is shown where fracturing is initiated

CONCLUSION

The well path of the second well was designed as a deviated well in the direction of minimum horizontal stress to optimize the performance of the doublet system. This means a maximization of flow rate over a duration of approximate 30 years with minimum temperature changes in the vicinity of the production well to omit a temperature short circuit in the doublet system.

The scheduled fracture treatments are designed to achieve an overall productivity index of at least 30 $m^3/(h\ MPa)$ to be sufficient for geothermal power production on an economic level.

ACKNOWLEDGEMENT

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