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Hydraulic history and current state of the deep geothermal reservoir Groß Schönebeck

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ABSTRACT

This study addresses the thermal–hydraulic–mechanical and chemical (THMC) behaviour of a research well doublet consisting of the injection well E GrSk 3/90 and the production well Gt GrSk 4/05 A(2) in the deep geothermal reservoir of Groß Schönebeck (north of Berlin, Germany). The reservoir is located between 3815 and 4247 m below sea level in the Lower Permian of the North German Basin (NGB).

Both wells were hydraulically stimulated to enhance productivity. For the production well three stimulation treatments were performed in 2007: these three treatments result in a productivity increase from 2.4 $m^3/(h\,MPa)$ to 14.7 $m^3/(h\,MPa)$. The injection well was stimulated four times in 2002/2003, resulting in a corresponding productivity increase from 0.97 $m^3/(h\,MPa)$ to 7.5 $m^3/(h\,MPa)$.

The necessary infrastructure for production and subsequent injection of geothermal fluid was established in June 2011. Between June 8, 2011 and November 8, 2013, 139 individual hydraulic tests were performed with produced/injected volumes ranging from 4.4 to 2567 m^3. The productivity index decreased non-linearly from 8.9 $m^3/(h\,MPa)$ on June 8, 2011 to 0.6 $m^3/(h\,MPa)$ on November 8, 2013. Five possible reasons for the productivity decrease are discussed: wellbore fill, wellbore skin, the sustainability of induced fractures, two phase flow and compartmentalisation. For all hydraulic tests, the injectivity index remains almost constant at 4.0 $m^3/(h\,MPa)$. During 17 of 139 hydraulic tests a sudden increase of the productivity was observed. Possible reasons for this effect are discussed: accumulation of free gas and/or fines and scales within the fracture as well as changing hydraulic properties due to changing mechanical load on the fracture.

1. Introduction

Geothermal energy can play an important role within the future energy supply (Sims et al., 2007), but the capability to access these resources depends on specific reservoir conditions. In high-enthalpy systems, direct use or conversion of extracted heat to electricity can be obtained at economically feasible costs. These resources are limited in most countries. Nonetheless there still exists enough heat in place in other environments to cover the heat demand for centuries. However, the initial productivity of the latter systems is often too low for an economically viable utilization without well stimulation. The efficient use of such systems is subject of current research and is covered under the technical term Enhanced or Engineered Geothermal Systems (EGS) (e.g. Tester et al., 2006).

As a test site (Fig. 1) for the provision of geothermal energy from a deep sedimentary basin in Germany, the research site at Groß Schönebeck located in the North German Basin has been developed. The site consists of a geothermal well doublet to access the sedimentary and volcanic layers of the Lower Permian (Rotliegend). The reservoir rocks are classified into two units: siliciclastic rocks (Upper Rotliegend) ranging from conglomerates (Havel subgroup) to fine-grained sandstones, siltstones and mudstones (Elbe subgroup), and volcanic rocks (Lower Rotliegend).

The target reservoir rocks are located at a depth of 3830–4250 m with a temperature of 150 °C (Zimmermann et al., 2011). The formation fluid contains high amounts of dissolved solids with mostly calcium, sodium and cloride as the major ions. Total amount of dissolved solids is 265 g/L (Wolfgramm et al., 2003).

An abandoned gas exploration well E GrSk 3/90 serves as injection well. The original gas exploration well with a depth of 4240 m was reopened and hydraulically tested in 2001. The test indicated a productivity index (PI) of 0.97 $m^3/(h\,MPa)$. Afterwards, the

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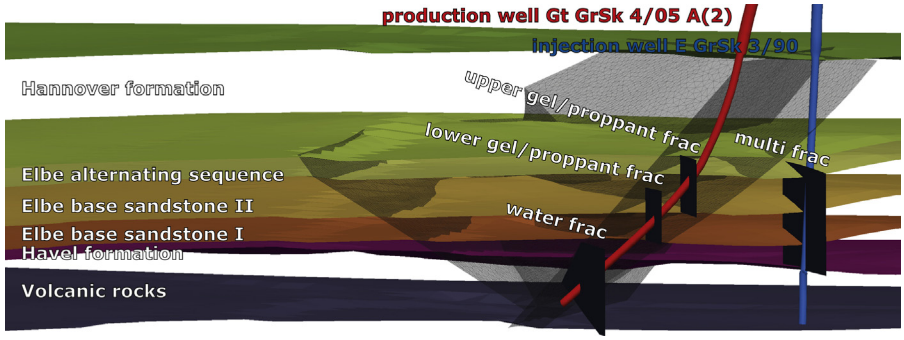

Fig. 1. Schematic of the Groß Schönebeck site including major geological units, fault zones, induced hydraulic fractures as well as production well Gt GrSk 4/05 A(2) and injection well E GrSk 3/90.

Table 1
Chronological sequence of all induced hydraulic fractures including treatment parameters, fracture dimensions and corresponding references (1 – Legarth et al. (2003), 2 – Legarth et al. (2005), 3 – Zimmermann et al. (2009), 4 – Zimmermann et al. (2010), 5 – Zimmermann and Reinicke (2010), 6 – Zimmermann et al. (2011), 7 – Blöcher et al. (2010)) in the injection well E GrSk 3/90 and the production well Gt GrSk 4/05 A(2).

Well		**E GrSk 3/90**						**Gt GrSk 4/05 A(2)**		
Treatment		Initial Frac	First gel/ Proppant frac	Second Frac	Second gel/ Proppant frac	First Water frac	Second Water frac	Water frac	First gel/ Proppant frac	Second gel/ Proppant frac
Date and time										
Year		2002	2002	2002	2002	2003	2003	2007	2007	2007
Duration	[h]	1.9	9.3	1.7	9.5	96	67	106.5	1.5	2
Treatment parameter										
Frac interval	[MD]	4140–4200	4140–4200	4088–4128	4088–4128	3883–4294	4135–4305	4350–4404	4204–4208	4118–4122
Completion		Open hole	Open hole	Open hole	Open hole	Open hole	Slotted liner	Slotted liner	Perforated liner	Perforated liner
Maximum flow rate	[m^3/h]	153 (stepwise)	138	121 (stepwise)	120	86.4	144	540	240	210
Cumulative volume	[m^3]	129	107	103	120	4284	7291	13,170	280	310
Maximum well head pressure	[MPa]	54.6	45.2	50.3	44.9	22	25	58.6	35	40
Gel type		HTU[a] / brine	HTU[a] / brine	HTU[a] / brine	HTU[a] / brine	–	–	–	Cross-linked	Cross-linked
Proppant type		–	Carbo-Lt	–	Carbo-Lt	–	–	Quartz sand	High strength	High strength
Proppant mesh size		–	2040	–	2040	–	–	2040	2040	2040
Proppant mass	[kg]	–	8796	–	8580	–	–	24,400	95,000	113,000
Fracture dimension										
Half length	[m]	–	32	–	–	–	160	190	57	60
Height	[m]	–	72	–	–	–	96	135	115	95
Aperture	[cm]	–	0.16	–	–	–	0.5	0.8	0.53	0.53
References		1,2	1,2	1,2	1,2	3	3	4	5,6	6,7

[a] Cationic, hydrophilic and polymer based gel.

well was deepened to 4309 m and stimulated in 2002 and 2003 (Legarth et al., 2003, 2005). The hydraulic treatment created a NE-SW trending sub-vertical fracture in the direction of the maximum horizontal stress (N18° E +/−3.7°) (Holl et al., 2005; Moeck et al., 2009) with a fracture half length of 160 m and a fracture height of 96 m according to the fracture simulation. A flow back test after the stimulation treatment in 2003 indicated an improvement of the PI to 7.5 m^3/(h MPa), being highly sensitive to formation

Table 2
Chronological sequence of well tests including hydraulic parameters, reservoir performance, productivity enhancement ratio (PER) and corresponding references (1 – Zimmermann et al. (2009), 2 – Zimmermann et al. (2010), 3 – Legarth et al. (2003), 4 – Legarth et al. (2005), 5 – Zimmermann et al. (2011)) in the injection well E GrSk 3/90 and the production well Gt GrSk 4/05 A(2).

Well		**E GrSk 3/90**					**Gt GrSk 4/05 A(2)**		
Well test		Casing lift	Casing lift	Casing lift	Flow back	Flow back	Injection	Casing lift	Casing lift
Date and time									
Year		2001	2002	2002	2003	2003	2007	2007	2009
Relative time		Before Initial Frac	After First Gel/proppant frac	After Second Gel/proppant frac	After First Water frac	After Second Water frac	Before Water frac	After Hydraulic Treatments	After Acidizing
Duration	[h]	12.24	8	13.92	5.76	24	13.4	11.8	4
Well test parameter									
Flow rate	[m^3/h]	13.5	14.8	22.4	59	35.8	31.6[a]	30.2	35
Cumulative volume	[m^3]	167	100	307	338	859	424[b]	356	140
Pressure difference	[MPa]	14	7.5	10.5	14.7	6.7	13.3	3.5	2.8
Reservoir performance									
PI/II	[m^3/(h MPa)]	0.97	2	2.1	4	7.5	2.4	10.1	14.7
PER		Initial	2.1	2.2	4.1	7.7	Initial	4.3	6.2
References		1,2	3,4	1,2	1,2	1,2	2	2	5

[a] Average of three single tests in different depths.
[b] Sum of three single tests in different depths.

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