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Review of the Hydraulic Development in the Multi-Reservoir / Multi-Well EGS Project of Soultz-sous-Forêts

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ABSTRACT

Over 20 years of research at the Soultz EGS project have led to the development of three vertically positioned reservoirs. They were explored in approximately 2, 3.6, 5 km depth by the 5 geothermal wells EPS1, GPK1, GPK2, GPK3, and GPK5. Natural injectivity of the three reservoir levels decreases with increasing depth from II = $9 \cdot 10^{-10}$ m^3 Pa^{-1} s^{-1} in the upper reservoir at GPK1 to II = $1\text{-}2 \cdot 10^{-10}$ m^3 Pa^{-1} s^{-1} in the deep reservoirs at GPK2 and GPK4.

In the framework of investigating possible stimulation success and temperature development under production condition, we have reviewed the complete hydraulic datasets of from 1988 to 2013. Stimulation experiments involve exclusively hydro-mechanic stimulation in the upper (GPK1) and intermediate (GPK1 and GPK2) reservoirs. Acidification using HCl and further chemical treatment has been applied to the three wells GPK2 to GPK4 reaching the deep reservoir. Our review shows that the most complete hydraulic history exists for GPK2.

In the intermediate reservoir, extraordinary hydraulic similarity between GPK1 and GPK2 is observed. Starting from a similar injectivity, a ratio between PI to II of 2:1 is obtained in first high volume stimulation. When productivity in GPK2 reached its maximum, a related improvement of GPK1 indicates good connection. The same ratio is reproduced when inverting the wells.

In the deep reservoir we conclude that most likely since 2003 or before, Soultz is operated in a multi-reservoir mode as revealed by hydraulic data in GPK2 due to the flow contributions from a fault zone in 3860m. The rather low production temperature since 2003 gives a further hint to this scenario. It can be considered as indicator of the complex flow field excluding a simple linear pressure or flow influence to the production temperature.

1. INTRODUCTION

The significance of the Soultz Enhanced Geothermal System (EGS) for the development of geothermal electricity production world-wide is unique with regard to different aspects. Successful EGS development started from the Soultz site on different reservoir levels evolving over three reservoir levels and employing about 20 major hydraulic and chemical stimulations, as well as 8 periods of long-term circulation under production condition. Electricity production at Soultz today is charged from the 5 km deep reservoir. This world-wide unique reservoir has been developed between 1999 and 2007 applying a total 16 different chemical and hydraulic injection operations.

The geological setting at Soultz is such that all three reservoirs are located in the granitic basement. This is due to a horst structure within the Upper Rhine Graben, URG, on which the site is located. The basement at Soultz reveals lithological changes. It is composed of two main granites. The upper part (from 1420 to 4700 m) is referred to K-Feldspar monzogranite, with a very altered and fractured intermediate section (between about 2700 and 3900 m) with fracture densities up to 2.86 m^{-1} (Dezayes et al., 2005). A correlation between alteration zones and permeable fractures as well as an increased tendency to shear during stimulation has been shown for this section (e.g. Evans et al., 2005). The deeper part of the basement (from 4700 to 5000 m) corresponds to a two-mica granite with fracture densities up to 1.97 m^{-1} (Dezayes et al., 2005). The upper reservoir extending from the top of the basement at 1420 m depth down to about 2000 m includes an about 100 m thick alteration zone at its top. This zone appears in different geological and geophysical characterizations, such as a zone of low magnetic susceptibility (Rummel and König, 1991) construed as paleo-weathering, a zone of high electric conductivity (Geiermann and Schill, 2010) interpreted to be caused by hydrothermal alteration, and a zone of high values of heat production of up to 7 $\mu W\ m^{-3}$ (Pribnow 2000; Grecksch et al. 2003).

The deep reservoir of Soultz fulfils most of the EGS criteria established by Garnish (2002). It should be noted that there is contribution of about 75 % of hydrothermal fluid to the reservoir from a regional field (Sanjuan et al., 2006). Major concern in the Soultz EGS development today is the relatively low total flow rate that has been limited during production mainly due to micro-seismicity (Cuenot et al., 2011) and more importantly, the high hydraulic impedance of the second production well GPK4. These two issues underline the motivation of this study to provide a review of the evolution of the hydraulic conditions of the different reservoirs with time and with respect to the different measures that have been taken.

2. DEVELOPMENT OF THE HYDRAULIC CONDITION AT SOULTZ

2.1 Natural injectivity

Natural injectivity indices (J) were measured in the three reservoir levels prior to any stimulation operation from single well injection tests. The upper reservoir was developed from GPK1 and tested with an injectivity of II = $9 \cdot 10^{-10}$ m^3 Pa^{-1} s^{-1} (e.g. Jung, 1991). Even higher injectivities were met in GPK2 for this reservoir, that are connected already to heavy mud losses during drilling of GPK2 at a depth of 2100 m. Jung et al., (1996) proposed an injectivity of II = $3{\cdot}10^{-8}$ m^3 Pa^{-1} s^{-1} from the pre-stimulation test 95FEB02.

In the intermediate reservoir, an injectivity of II = $3\text{-}6{\cdot}10^{-10}$ m^3 Pa^{-1} s^{-1} was observed for GPK1 and GPK2 from a series of well tests described below (Jung et al., 1995). Injectivities in the deep reservoir determined from GPK2 (and GPK4) reveal a factor 3 to 4 lower values of II = $1\text{-}2{\cdot}10^{-10}$ m^3 Pa^{-1} s^{-1} (Weidler, 2001; Tischner et al., 2007).

All these values are related the hydraulic procedures performed in Soultz at that time. Injection tests have preceded typically any other hydraulic experiment. There are other values which however do not represent the natural conditions. As such, the initial conditions at GPK3 were determined during highly perturbed hydraulic situation: 1) there was only a productivity test that results generally in higher values, 2) the well was targeted in the already stimulated zone around GPK2 and possibly influenced from these operations and 3) the productivity test performed ultimately in this deep reservoir is possibly influenced directly from GPK2 since the values are not determined during a single well tests but circulation testing from GPK2 to GPK3. The related GPK3 value is one order of magnitude higher (PI = $2{\cdot}10^{-9}$ m^3 Pa^{-1} s^{-1}; Hettkamp et al., 2004) than GPK2. There are no comparable single well determinations of GPK3. Figure 1 illustrates the apparent decrease in the natural injectivity index occurring with increasing depth. Such distribution is not unexpected and follows a pattern from various other authors. The world-wide and specific the URG region compilations of hydraulic conductivity in the crystalline basement Ignebritsen and Mannig, 1999 and Stober and Bucher, 2007 have similar results, however mostly at lower absolute values.

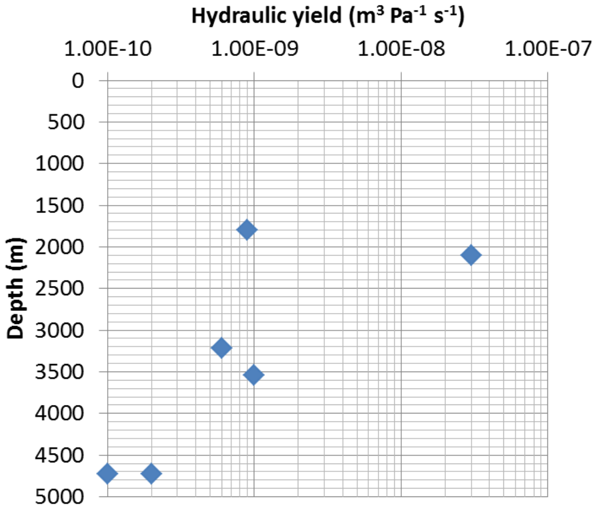

Figure 1: Injectivity and productivity indexes of the non-stimulated reservoirs I-III measured in single well tests in GPK1, GPK2 and GPK4 (91JUL18; 93AUG19; 00FEB25; 04SEP08) and under circulation conditions between GPK3 and GPK2 (03MAR14), respectively (data after Jung, 1991; Jung et al, 1995; Weidler 2001; Hettkamp et al., 2004; Tischner et al., 2007).

2.2 Development of injectivity and productivity in the intermediate reservoir

Next, only the evolution of the hydraulic condition in the intermediate reservoir (II) is reviewed. It involved only the GPK1-GPK2 doublet system, a layout typically realised in the follow-up projects in the Upper Rhine valley within a similar depth range of approx. 2.5-4.0 km. Along the 2850-3590m long open hole section of GPK1, a hydrothermally altered and hydraulically significant fault intersects the well at 3480 m depth. Using flow rates of 0.4 L s^{-1}, an injectivity of II = $5\text{-}7{\cdot}10^{-10}$ m^3 Pa^{-1} s^{-1} was inferred (**Error! Reference source not found.**, Jung et al., 1995). Plugging the lower part of the open-hole section with sand to a depth of 3400 m in the tests in 1993 led a reduction of initial injectivity by one order of magnitude (Jung et al, 1995). It should be mentioned that initially GPK1 was operated as a producer. Initially in 1994, EPS-1 was configured as injector during the experiments and later GPK2. After the 95AUG15 experiment reverse operation with GPK1 as injector and GPK2 as producer were started.

Two hydro-mechanic stimulations were carried out successfully at GPK1 and three stimulations in GPK2 in the intermediate reservoir between 01-Sep-93 and 18-Sep-96 (Table 1). First stimulations were meant to increase the hydraulic transmissivity in the upper part of the open-hole section. Two stimulations (93AUG19; 93OCT01) employing packers to separate the lower part failed.

Table 1: Overview of the hydro-mechanic stimulations in the intermediate reservoir (II) at the Soultz-sous-Forêts EGS site (France; Jung et al., 1995; Weidler, 2001; Hettkamp et al., 2004; Tischner et al., 2007).

Stimulation	Open hole section (m)	Injected volume (m^3)	Flow rate (L s^{-1})
93AUG19	Bottom-hole packer test		1.6-6
93SEP01	2850-3400 (GPK1)	25300	0,15-36
93OCT01	Packer test on 3490 m fault		
93OCT11	2850-3590 (GPK1)	19300	40-50
95JUN14	3210-3876 (GPK2)	624	30

95JUN16	3210-3876 (GPK2)	28000	12-56
96SEP18	3200-3876 (GPK2)	27004	25-78

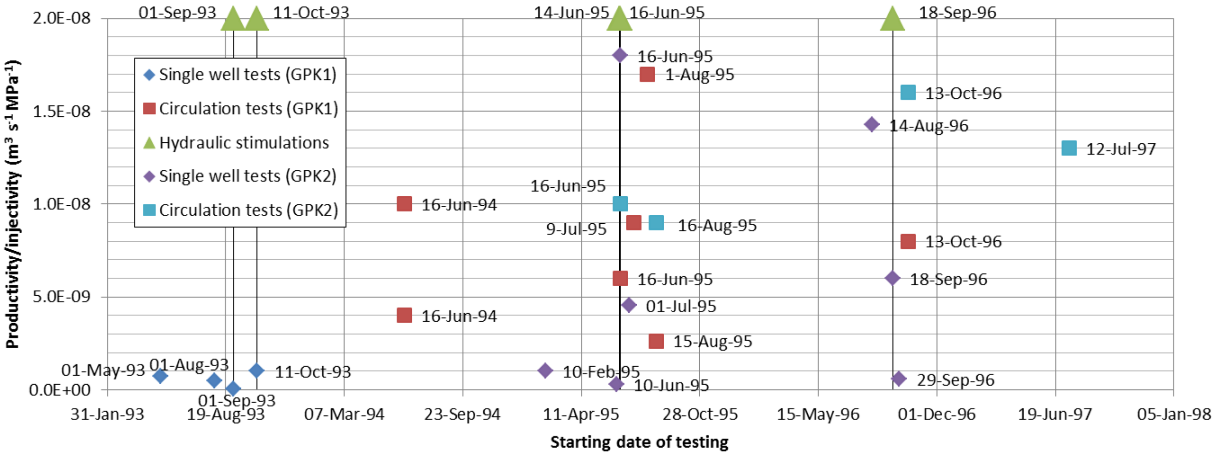

Figure 2: Injectivity and productivity indexes of the intermediate reservoir (II) measured during single well injection tests and circulation production tests, except from 96AUG14 that represents a single well production test. For testing over several days the starting day of the test is labelled (data after Jung et al, 1995; Weidler, 2001; Hettkamp et al., 2004; Tischner et al., 2007).

After stimulation at high volume and high flow rates (50 L s^{-1}) of the entire open hole section of GPK1 (93OCT11), representing matrix and major fracture zone, a differential pressure of similar to the 93SEP01 injection test has been observed, leading to an injectivity of $II = 1 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}, i.e. an improvement of factor "2" compared to natural condition from 93AUG01 test and reaching the natural condition of the upper reservoir. A production test was carried out in GPK1 when circulating 6200 m^3 using EPS1 as injector. The differential pressure of 3.4 MPa at a flow rate of 18.5 L s^{-1} was interpreted in terms of productivity as $4 \cdot 10^{-9}$ or $10 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1} (Hettkamp et al., 1999 and Jung et al., 1995, respectively). The productivity has been confirmed one year later in the test 95JUN16 carried out prior to the stimulation of GPK2 (Hettkamp et al., 1999).

In GPK2 also an additional low volume stimulation (95JUN14) at a flow rate of 30 L s^{-1} yielding a differential pressure of 12.2 MPa has been carried out preceding stimulation 95JUN16 (Jung et al., 1996). In this stimulation, flow rate reached maximum 56 L s^{-1} (Jung et al, 1996). Subsequently GPK2 was used as injector. Productivity of GPK1 has been continuously monitored during the following circulation tests. With respect to the initial injectivity (93AUG01 and 93SEP01), maximum productivity is observed in the 95AUG01 test after circulating over a total of about 40 days. A second stimulation of GPK2 was performed (96SEP18) after productive fractures had been progressively plugged during the test 95AUG15 by re-injecting unfiltered brine into GPK2 and productivity had dropped to $PI = 2.6 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1} (Gérard et al., 1997). Interestingly, GPK2 injectivity (95AUG16) is less affected by clogging compared to GPK1 productivity (95AUG15).

While productivity in the 96AUG14 test in GPK2 increased by a factor "1.5" the value during the reversed circulation experiment after 95AUG15, injectivity during the 96SEP18 stimulation is less than half of the 96AUG14 productivity. The 96SEP18 stimulation was carried out in the open-hole section between 3200-3650 m. A volume of 28'000 m^3 was stepwise injected at flow rates using Q = 25-45-78 L s^{-1} (Gérard et al., 1997). Injectivity after stimulation dropped to values in the order of the initial injectivity of the well (95FEB10, 95JUN10, Jung et al, 1996). Productivity under circulation condition in the short-term tests of 96OCT13 and the four month long-term circulation 97JUL12 reveal productivities comparable to the single-well production test 96AUG14.

It can be summarized that both wells show an extraordinary related behaviour. Initially, they start with a similar natural injectivity obtained from single-well tests in the undisturbed reservoir. High volume stimulation tests with step-wise increased flow rates up to 50 and 56 L s^{-1} in GPK1 and GPK2, respectively, leads to similar improvement of productivity in the order of $PI = 5 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1} to $PI = 1 \cdot 10^{-8}$ m^3 Pa^{-1} s^{-1}. When productivity in GPK2 reached a maximum of $PI = 1.8 \cdot 10^{-8}$ m^3 Pa^{-1} s^{-1} after stimulation, a related improvement of GPK1 conditions were observed. Without any stimulation a productivity of $PI = 1.7 \cdot 10^{-8}$ m^3 Pa^{-1} s^{-1} under circulation condition was reached, thus indicating a good connection. It also provides a first indication that different hydraulic conditions are met under a single well or a circulation regime. This common history may be disturbed by the partial clogging during the 95AUG15 experiment (described above) when GPK2 injectivity drops by almost one order of magnitude and GPK1 productivity (95AUG16) remains stable with respect to 95JUN16 values. High volume stimulation and step-wise increase of flow rates to 78 L s^{-1} results in a recovery of the general reservoir condition to almost the productivity observed in summer 1995. For both constellations, i.e. GPK1 production and GPK2 injection in 1995 and GPK2 production and GPK1 injection in 1996, the productivity is twice the injectivity. The general performance of the reservoir has been confirmed by the long-term circulation in 1997.

2.3 Development of injectivity and productivity in the deep reservoir (GPK2)

For the deep reservoir, Nami et al. (2008) summarized the results of the hydro-mechanic stimulation and the different specific chemical stimulations. A high impact of hydraulic over HCl stimulation on the productivity or injectivity is observed for GPK2 and

GPK3. In GPK4, however, chemical stimulation of different types appears to builds up > 50 % of the post-stimulation productivity (Nami et al., 2008). In GPK2 two hydro-mechanic stimulations and one acidification using HCl have been performed resulting in an injectivity of $II = 3.5 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}. GPK3 was treated additionally with organic clay acid. GPK4 was moderately stimulated hydraulically and treated additionally with the above mentioned chemicals and regular mud acid and chelatants. Observed injectivities after HCl treatment suggest an increase by about $\Delta II = 0\text{-}1.5 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1} for the different wells. Further chemical treatments suggest an increase to a final injectivity around $II = 4 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}. The effective contribution of chemical treatment in GPK4 is, however, unclear since there is strong evidence for considerable contribution through casing leaks (Pfender et al., 2006). Further investigation would require application of sophisticated well-simulator models.

With regard to hydro-mechanic stimulation, increase in productivity throughout the intermediate and deep reservoir was most effective using high volume stimulation (> about 20’000 m^3) with flow rates in the order of up to about 50 L s^{-1} causing differential pressures in the order of about 12-13 MPa in both reservoirs of GPK2. During moderate stimulation using about 10’000 m^3 at slightly lower flow rates (up to 45 L s^{-1}), differential pressures of up to 19 MPa are observed in GPK4 resulting in an injectivity of $II = 2 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}, about half the value achieved in GPK2.

The development of the hydraulic yield of GPK2 is shown in Figure 3, representing the most complete history of hydraulic tests in the intermediate and deep reservoir. The stimulation operations that have been carried out in the well are listed in Table 2. Clearly, the initial injectivity of the deeper reservoir is about half that one of the intermediate reservoir. First hydro-mechanic stimulation of the deep reservoir with comparable flow rates (up to 50 L s^{-1}) and volumes (00JUN30) leads to an increase of injectivity by one order of magnitude to $II = 4 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}. With respect to hydro-mechanic stimulation HCl-treatment reveals a contribution of 20% to $II = 5 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}. These values can be related to the change in PI, hydraulic high volume stimulation with very high peak flow rates (up to 90 L s^{-1}) of short duration (few hours) leads to $PI = 1 \cdot 10^{-8}$ m^3 Pa^{-1} s^{-1}. This is comparable to the values that have been obtained by high volume hydro-mechanic stimulation with flow rates of up to 50 L s^{-1}, corresponding to a differential pressure of about 10-12 MPa. This productivity is reproducible in the long-term circulation test of 2005, which lasted over a period of 175 days. Productivities that are comparable to the peak flow rate stimulation in the intermediate reservoir are obtained after about 650 days of long-term circulation in the years 2008-2010. A prominent increase of long-term circulation on productivity is reflected in the continuous increase in productivity in 2011 after a total number of 793 days of circulation.

Table 2: Overview of the hydro-mechanic stimulations in the intermediate reservoir (II) at the Soultz-sous-Forêts EGS site (France; Weidler, 2001; Hettkamp et al., 2004; Tischner et al., 2007).

Stimulation	Open hole section (m)	Injected volume (m^3)	Flow rate (L s^{-1})
00JUN30	4400-5050 (GPK2)	23400	30-50
03FEB13	4400-5050 (GPK2)	5814 (HCl)	30
03MAY27	4400-5050 (GPK2/GPK3)	34000	30-90

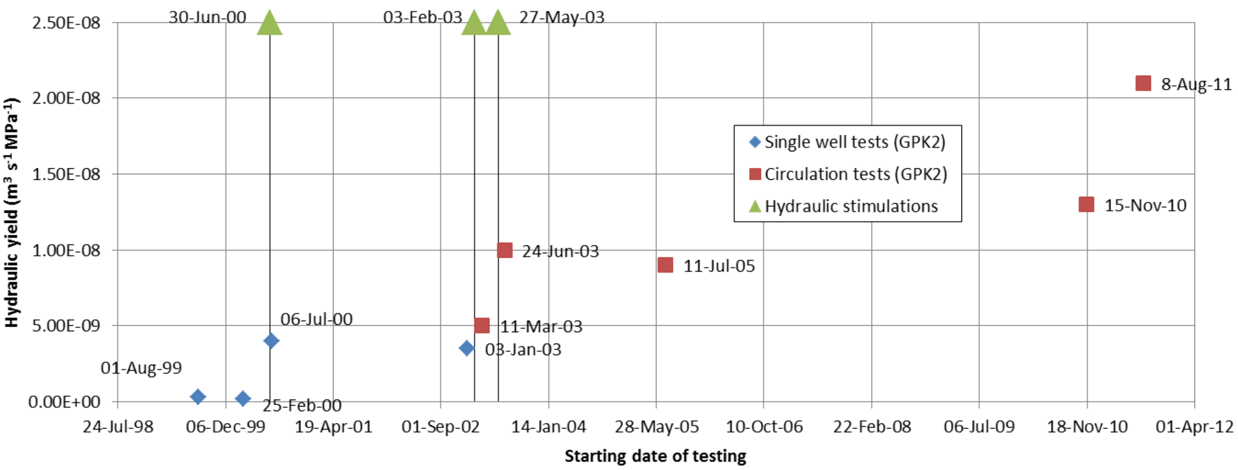

Figure 3: Injectivity and productivity indexes GPK2 in the deep reservoir (iii) measured during single well injection tests and circulation production tests, except from 03MAR11 representing a circulation injection test. For testing over several days the starting day of the test is labelled (data after Weidler, 2001; Hettkamp et al., 2004; Tischner et al., 2007). The values of the years 2010 and 2011 originate from long-term circulation during production.

The importance of a casing leakage as origin of the hydraulic yield of GPK2 has been discussed. When GPK2 was completed down to 4403 m the earlier open-hole section of the intermediate reservoir was cased. In this part, only one flow log at beginning of the 00JUN30 experiment (see below) was run. After loss of a logging tool after the flow log, a casing restriction has been detected at ~3890 m depth, next to the depth of well deviation and opposite to a fault zone at the bottom of the intermediate reservoir. Pfender et al. (2006) propose three major flow zones in the inaccessible deep part of GPK2 using brine displacement analyses: Two are located in the vicinity of the casing shoe at 4420 m / 4670 m depth, taking up 15% / 70% of the flow, and one in the cased section at 3860 m taking up 15% of the flow (Jung et al., 2010). Therewith, this leakage provides a considerable contribution to the injectivity of the GPK2. The PI obtained from circulation tests in 03JUN24 and from the long-term circulation 05JUL11 agrees with the total injectivity for GPK2 of $II_{TOT} = 1 \cdot 10^{-8}$ m^3 Pa^{-1} s^{-1} determined from 06MAR13. With a contribution of $II_{CS} = 1.7 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1} from the cased hole, the injectivity of the deep reservoir can be corrected to be $II = 8.3 \cdot 10^{-9}$ m^3 Pa^{-1} s^{-1}. Jung et al., (2010) concluded that instantaneous reaction to pressure changes indicates the influence of near well domain rather than from the fracture zone aligning with this leak. The flow log run at GPK2 in the intermediate reservoir after stimulation experiment 96SEP18 provides a further hint since it reveals only the discharge from depths above 3550 m.

Table 3: Main circulation phases with respective mean operational parameters (2008-2013). Due to failure of sensors in early 2013, only the circulation period of 13APR01 to 13JUN17 is listed. ESP: Electro-submersible pump (production), LSP: Line-shaft pump (production), IP: Injection pump.

Well	Type of operation	Flow rate (L s^{-1})	Temperature (°C)	Well-head Pressure (MPa)
Test 2008-1: 27th July to 17th August 2008				
GPK2		25	163	
GPK3		23	60	7.3
Test 2008-2: 03th to 16th December 2008				
GPK2		17	160	
GPK3	IP	27.5	68	8.6
GPK4	ESP	12	153	
Test 2009: March to October 2009 (240 days)				
GPK1	gravity	2	70	≤ 1
GPK2	LSP	20	156	2
GPK3	IP	10	73	2 - 6
GPK4	ESP	8	147	≤ 2
Test 2009/2010: December 2009 to November 2010 (323 days)				
GPK1	gravity	2	50	0.3
GPK2	LSP	18	164	1.8
GPK3	IP	15	66	4.7
GPK4	not in operation			1.3
Test 2010/2011: December 2010 to April 2011 (90 days)				
GPK1	gravity	11	75	0.5
GPK2	LSP	22	159.3	1.9
GPK3	IP not in operation	9	75	1.8
GPK4	not in operation			
Test 2011-2: August to October 2011 (70 days)				
GPK1	gravity	12	75	0.4
GPK2	LSP	23	157.5	2
GPK3	IP not in operation	9	75	1.6
GPK4	not in operation			
Test 2012: 20-23rd April 2012 (3 days)				
GPK1	gravity	6	55	0.1
GPK2	LSP	21	156	2
GPK3	IP not in operation	15	55	0.8
GPK4	not in operation			
Test 2013: April to June 2013 (78 days)				
GPK1	not in operation			
GPK2	LSP	15	157.5	2
GPK3 / GPK4	IP not in operation	12	60	0.25

Since II_{TOT} determined from brine displacement analyses in GPK2 equals PI under circulation conditions, we make the first order assessment that the distribution of productivity from the open hole section and the cased section of the well is distributed similarly. Next we discuss, at which stage of the operation the leakage became hydraulically active using production temperature variations. . They vary clearly from the unperturbed reservoir temperature of 200°C. During production of GPK2 between 2003 and 2013, well head temperatures ranges from 152°C in 2003 after high volume stimulation (Baumgärtner et al., 2005) over 156 °C in 2009 to 164 °C in 2009/2010 (Table 3). A remarkable change of temperature in this time period that could indicate the onset of leakage is not identified (Figure 4). Thus, we assume that leakage was initiated before 2003. As such, the spinner log in the open hole section at the beginning of stimulation 00JUN30 indicated outlets near 4430 m (10 %), 4780 m (20 %), 4890 m (17 %) and below 4950 m (52 %) (Baria et al., 2002). The log interpretation suffers from the absence of a caliper profile below 4610 m (Evans et al., 2008). A significant contribution from the cased section was not observed at this stage. This indicates that the initial injectivities represent contribution from the deep reservoir, only.

In any case, the characterization of the deep reservoir in terms of productivity needs to be corrected by at least the value of II_{CS}. It is most likely, that improvement of PI during the long-term circulation is due to both, the deep and the intermediate reservoir.

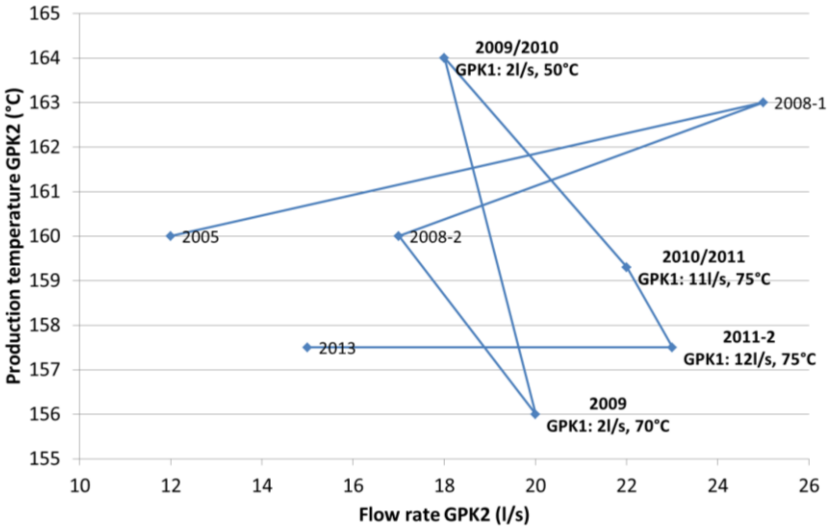

Figure 4: Relation between production temperature and flow rate in GPK2 over time and with respect to the injection in GPK1 between 2008 and 2013. Due to failure of sensors in early 2013, only the circulation period of 13APR01 to 13JUN17 has been used. In 2012 temperature equilibrium has not been reached. During circulation in 2008-1, 2008-2 and 2013, no injection into GPK1 occurred.

Although in the 06MAR13 test no connection to the fault zone has been observed (Jung et al., 2010), a temperature cooling effect observed at GPK2 related to a simultaneous reinjection into GPK1 has been suspected on the basis of the development of temperature with respect to injection rate into GPK1 between 2010 and 2011 (Genter et al., 2013; Dentzer and Bruel, 2013). Circulation in 2012 und full production condition (using the LSP pump) lasted only a few days and thus, temperature equilibrium had not been reached. Since such an effect would limit the possibilities of operating the site using a multi-well and multi-reservoir concept, we have investigated the relation between flow rate, production temperature, injection rate and temperature into GPK1 and its development during production between 2008 and 2013 listed in Table 3. In Figure 4 the relation between production temperature and flow rate in GPK2 over time and with respect to the injection in GPK1 between 2008 and 2013 is shown. Data from 2012 and the circulation period before 13APR01 have been neglected due to sensor failure and non-equilibrium of production temperature, respectively. Neither an obvious correlation between flow rate and production temperature is observed, nor can a continuous development over time or a function of the injection rate into GPK1 be inferred over a period of 6 years of circulation.

3. CONCLUSION

In the intermediate reservoir, extraordinary hydraulic similarity between GPK1 and GPK2 is observed. Starting from a similar injectivity, a ratio between PI to II of 2:1 is obtained by high volume stimulation tests with step-wise increased flow rates up to about 50 L s^{-1} in GPK1 and GPK2, respectively. When productivity in GPK2 reached its maximum after stimulation, a related improvement of GPK1 conditions was observed indicating a good connection. It provides a first indication that different hydraulic conditions are met under a single well or a circulation regime. The same ratio is reproduced when inverting the wells after high volume stimulation with step-wise increase of flow rates to 78 L s^{-1}.

Our review shows that the most complete hydraulic history exists for GPK2. This involves all three reservoirs. In the most interesting intermediate and deep reservoirs, a detailed analysis of the hydraulic development is a major challenge.

- In GPK2, temporal containment of the occurrence of leakage allows for an estimate of its contribution to the total productivity, only.
- The casing leakages in GPK4 occur in the deep reservoir, but no high volume hydro-mechanic stimulation has been applied to this well.
- Due to GPK3 targeting the stimulated zone of GPK2, no natural injectivity was acquired for this well.

Most likely since 2003 or before, Soultz is operated in a multi-reservoir mode as revealed by hydraulic data in GPK2 due to the flow contributions from a fault zone in 3860m. Also the rather low production temperature since production start in 2003 gives a hint to this scenario. Further sophisticated analyses using borehole simulators are necessary. The rather random distribution of production temperature can be considered as indicator of the complex flow field. Flow can be expected to vary with pressure due to non-laminar flow conditions or to mechanical interaction. Such scenario excludes a simple linear pressure or flow influence to the production temperature.

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