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EFFECT OF THE USE OF BRINE FOR THE INITIAL PHASE OF THE GPK2 AND GPK3 STIMULATION TESTS

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ABSTRACT

Controlling the hydraulic pressure profile in the borehole during a stimulation test and knowing the failure pressures of the fractures in the depth range of the open-hole section are two important tasks of the stimulation technique. With the numerical borehole tool HEX-B the downhole data for pressure and temperature taken during the stimulation tests at GPK2 in June 2000 and GPK3 in May 2003 has been interpreted. The comparison of the time-history of near-borehole events of the test at GPK2 with the downhole pressure development in the open-hole sections implied that the use of the heavy brine had a supporting effect for the stimulation of the bottom part of GPK2. The corresponding analysis for the GPK3 test showed that the failure pressure of the fractures of the bottom part have never exceeded during the presence of the heavy brine in the well and therefore no effect due to the brine could have been reached.

INTRODUCTION

Currently, hydraulic stimulation is the method used to create an underground heat exchanger of lowest possible hydraulic resistance for an EGS of the Hot Fractured Rock type, with three principal aims:

1. Improvement of the injectivity/productivity of the boreholes to achieve an economical and reliable circulation rate;

2. Preferential improvement of the deepest flow paths intersecting the wells, the production wells in particular, for a production temperature as high as possible;

3. Improvement of the permeability of the host rock distributed as widely and regularly as possible to avoid thermal short circuits between the injection and production boreholes.

Subsurface heat exchangers of EGS plant will be typically situated at depths where the main contributions to permeability are from fractured structures. Therefore, improving permeability of the host rock mass usually means increasing the apertures of natural fractures by bringing them to fail and shear through hydraulic over-pressurising. Technically the overpressure in the subsurface can only be controlled from the surface by varying the pumping rate, the duration of different injection steps and by varying the density of the fluid. The density can be influenced by control of its dissolved solids content (NaCl at Soultz) and, less feasibly, of its temperature.

During the initial phase of a stimulation usually brine is injected to open predominately the fractures in the deeper part of the reservoir. In the present paper the effect of the brine injection is analysed using the data from the stimulation tests 00jun30 on GPK2 and from the stimulation test 03may27 on GPK3. Two kind of results will be discussed:

1. Effect of the absolute down-hole pressure to the near-borehole microseismicity;

2. Effect of the brine to the near-borehole microseismicity.

RESULTS

Microseismic events during an injection test can bee interpreted as the failure of fractures due to an increase of the hydraulic pressure. Near-borehole events can be regarded as fracture failures due to an absolute hydraulic pressure which corresponds with the borehole pressure at time and depth the events occur.

The pressure values at a specific depth and time has been calculated with the numerical borehole tool HEX-B which allows to determine the borehole profiles for temperature and pressure using the measured wellhead data for flow rate, pressure, NaCl-molality and fluid temperature. The model parameters used and the processes implemented are described in detail in Mégel et al., 2005.

Effect of the absolute down-hole pressure to the near-borehole microseismicity

For both stimulation tests, 03jun27 in GPK3 and03may27 on GPK3, near-borehole events with a horizontal distance of 25 m and 50 m from the open-hole sections have been extracted (Fig. 1 and Fig. 2).

Since the stimulation 03jun27 in GPK3 started with a continuous increase of the downhole pressure during the first 24 hours each of the near-borehole events can be identified with a specific failure pressure. This allows to determine a depth dependant fracture failure pressure for GPK3 (Fig. 3).

In contrary the stimulation test 00jun30 at GPK2 started immediately with a downhole pressure from 55 MPa to 62 MPa within a depth range between 4400m and 5100m (Fig. 4, blue colour). Hence all near-borehole fractures at each depth saw a hydraulic pressure above their failure pressure from the start and the microseismic events occurred along the whole open hole section of GPK2 nearly immediately (Fig. 4). Therefore a depth dependent failure pressure analysis as carried out for the GPK3 stimulation 03may27 was not possible.

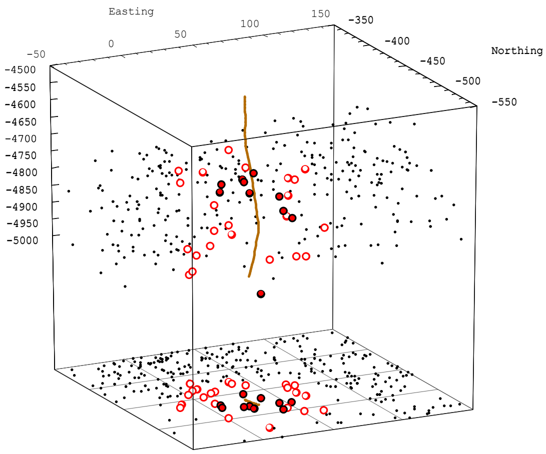

Fig. 1: Microseismic events for the first 24 hours of the GPK3 stimulation 03may27 with a horizontal distance from the borehole trajectory within 25 m (filled red dots), between 25 m and 50 m (red circles) and above 50 m (black dots). Shown also are vertical projection of the event locations on the bottom face.

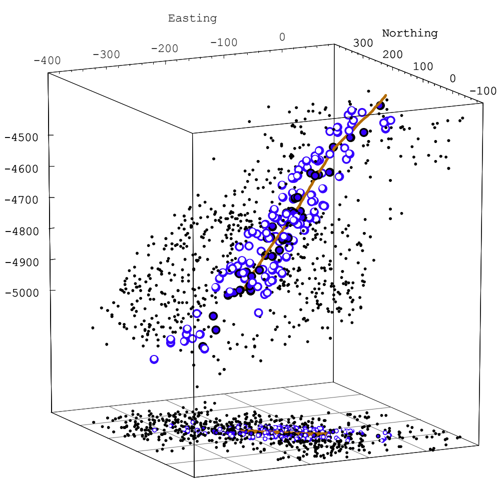

Fig. 2: Microseismic events for the first 24 hours of the GPK2 stimulation 00jun30 with a horizontal distance from the borehole trajectory within 25 m (filled blue dots), between 25 m and 50 m (blue circles) and above 50 m (black dots). Shown also are vertical projections of the event locations on to the bottom face.

Two main results can be observed:

1. The failure pressure for the near-borehole events in GPK3 increase between a depth of 4700 m and 5100 m from 52 MPa to 60 MPa. Since we can assume that the fracture orientations have a certain regular distribution along the open hole section and furthermore, a general linear increase of the friction coefficient by a factor of over 1.5 within this depth range is rather unlikely, this increase of the failure pressure must reflect the depth dependency of the stress field.

2. For a specific depth the variation in hydraulic failure pressure lies within a range of 2 to 5 MPa. The variation is probably due at least partly to the variability of fracture orientations at that specific depth.

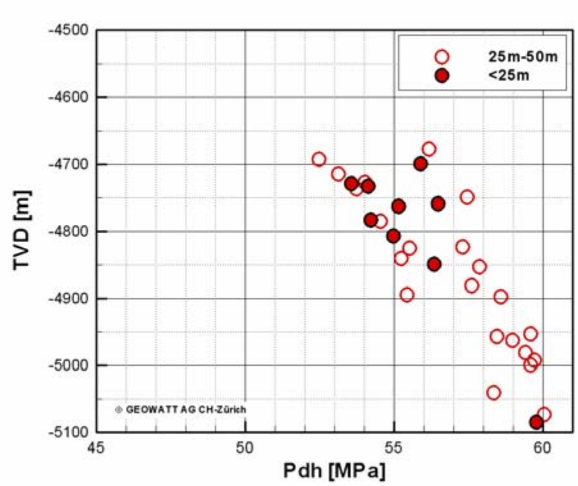

Fig. 3: Borehole pressure at time and depth of near-borehole microseismic events (horizontal distance to the borehole <25m and 25m-50m) during the first 24 hours of the GPK3 stimulation test 03may27

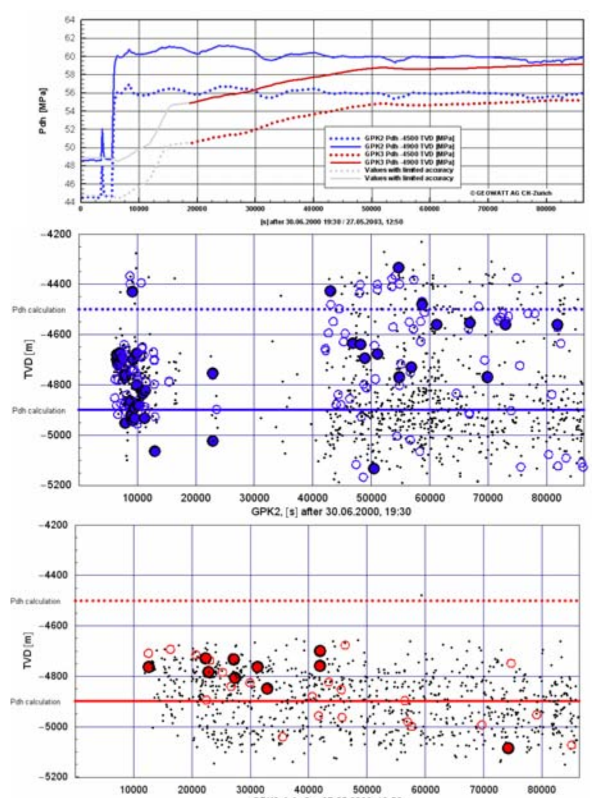

Fig. 4: Top: Downhole pressure in 4500 m TVD and 4900 m TVD for the first 24 hours, for GPK2 (blue) and GPK3 (red). Middle and bottom: Microseismic events with a horizontal distance from the trajectory within 25 m (filled dots), between 25 m and 50 m (circles) and above 50 m (black dots), for GPK2 (blue) and GPK3 (red).

Effect of the brine to the near-borehole microseismicity

The aim of injecting NaCl brine is to increase the pressure gradient in the open hole section so that the deepest fractures will tend to be the first to shear. The absolute fracture failure pressure determined for the GPK3 stimulation 03may27 has a gradient between about 5 MPa/400m to 10 MPa/400m (Fig. 3). The injection of NaCl-saturated brine in the first phase of the injection test at GPK2 and GPK3 produced a maximum pressure gradient respectively of 4.6 MPa/400m in GPK2 and 4.4 MPa/400m in GPK3 (see Fig. 5 and Fig. 6 respectively), both of which lie close to the failure pressure gradient derived from the GPK3 stimulation and plotted in Fig. 3.

If freshwater had been injected instead of brine the hydraulic pressure gradient would have been 0.7 MPa/400m lower in GPK2 (Fig. 5) and 0.6 MPa/400m in GPK3 (Fig. 6), assuming the same flow impedances into the reservoir as determined for the corresponding brine injection. Although the effect of the NaCl-brine injection is only minor the use of NaCl-brine brings the hydraulic gradient to the proximity of the most favourable pressure gradient for fractured failure carried out for the GPK3 stimulation (Fig. 3).

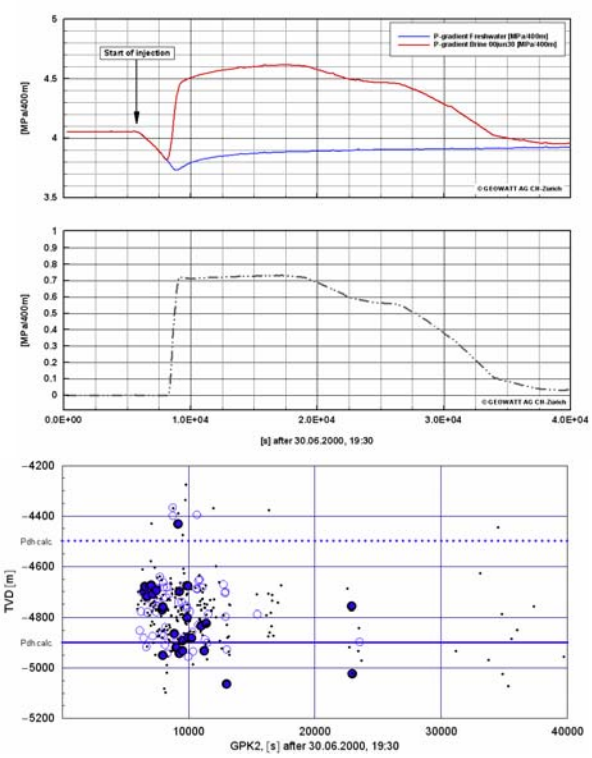

Fig. 5: Top: Pressure difference between –4500 m TVD and –4900 m TVD for the first 10 hours in GPK2, for brine used at the test 00jun30 and for a fictive injection of freshwater Middle: Difference between the pressure gradients in the open hole section of GPK2 due to brine and freshwater injection. Bottom: Microseismic events with a horizontal distance from the GPK2-trajectory within 25 m (filled dots), between 25 m and 50 m (circles) and above 50 m (black dots)

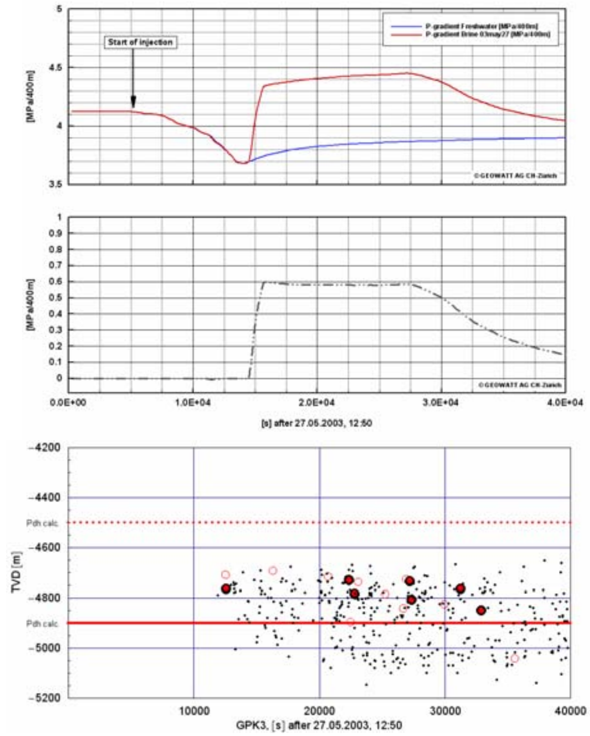

Fig. 6: Top: Pressure difference between –4500 m TVD and –4900 m TVD for the first 10 hours in GPK3, for brine used at the test 03may27 and for a fictive injection of freshwater Middle: Difference between the pressure gradients in the open hole section of GPK3 due to brine and freshwater injection. Bottom: Microseismic events with a horizontal distance from the GPK3-trajectory within 25 m (filled dots), between 25 m and 50 m (circles) and above 50 m (black dots)

CONCLUSIONS

The locations of the microseismic events have a limited accuracy. The selection of near-borehole events is therefore rather vague. Nevertheless some considerations about the role of the NaCl-injection during the stimulation tests at GPK2 and GPK3 shall be made:

1. Considering only the event locations during the GPK2 stimulation test 00jun30 with a horizontal distance below 25 m from the borehole a predominant downward shift of the events can be observed just starting at the time the steeper pressure gradient due to the injected brine becomes evident in the open hole section (Fig. 5). Assuming the depth dependant failure pressure derived from the data of GPK3 are also valid for GPK2, the absolute downhole pressure in GPK2 was above the failure pressure for all fractures along the entire open hole section from the start of the injection test (Fig. 3). Therefore the downward shift of the events could be in fact a result of the injection of the brine.

2. A significant downward shift of the events can not be observed for the GPK3 stimulation test 03may27 (Fig. 6). During the period the increased pressure gradient due to the brine injection was active the absolute downhole pressure at the depth of –4900 m TVD was at any time below 56 MPa. Therefore the

failure pressure of the fractures in GPK3 below –4850 m TVD has never been exceeded (Fig. 3)

Despite the fact that the failure behaviour of fractures along a given borehole is rather uncertain the use of brine at the start of an injection increases at least the probability of success.

REFERENCES

Mégel, T., Kohl, T., Gérard, A., Rybach, L., Hopkirk, R. (2005), Downhole pressures derived from wellhead measurements during hydraulic experiments. *Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005*

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