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New Concepts for Extracting Geothermal Energy from One Well: The GeneSys-Project

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ABSTRACT

In Germany, doublet-systems that consist of one production and well one injection well are usually installed to recover geothermal energy from great depths. However, the "GeneSys" project aims to develop a single well concept for direct use of geothermal energy. In this concept, the production and injection wells are realized within the same well.

The 4000 m deep Horstberg well is located in the Northern German Basin and serves as a geothermal test well. A large hydraulic fracture was created there in a low permeabilty formation (Middle Bunter) by applying performing a massive hydraulic fracturing operation. The good hydraulic properties of the fracture and the hydraulic link formed between two layers of the Middle Bunter are the basis for two different schemes: a circulation scheme between the two layers and a huff-puff scheme. The huff-puff operation mode is the cyclic injection of cold water into the fracture and production of the heated water after a certain recovery time.

Both concepts have been tested successfully at Horstberg. The thermal output was higher than 1 MW_{th}, which is sufficient to supply large office buildings with geothermal heat. In June 2009, the drilling operation for a deep well was initiated in Hannover. It is intended to supply the buildings of the Geozentrum Hannover with heat using one of the tested single well concepts.

1. INTRODUCTION

In many cases, natural rock permeability is the critical parameter in geothermal resource exploitation. Two regions in Germany, which are characterized by highly conductive structures located deep underground, are most favorable for geothermal projects: The Upper Rhine Valley in southwestern Germany and the Molasse Basin in southern Germany. However, in most regions of Germany, low permeability rock dominates, and geothermal energy cannot be gained under present economic conditions.

The GeneSys project aims to extract the heat from low permeability sedimentary rock. The challenges of the project are at least twofold:

- Creation of large artificial fractures in sedimentary rock
- Development and realization of a single well concept

It is intended to provide geothermal energy for the heat supply of the GEOZENTRUM Hannover, where a thermal power of 2 MW_{th} is required. A single well concept, or injection and production within one wellbore, is intended here for economical reasons: the low energy output of 2 MW_{th} does not justify a cost intensive doublet scheme with two deep wells. Another more general motivation is that the chances and risks of new recovery concepts should be tested.

The overall GeneSys-project comprises two individual projects: a research project focused on testing and development concepts at the abandoned "Horstberg" gas well and the demonstration project at the Geozentrum Hannover. An overview of the tests performed in "Horstberg" and of the plans for the demonstration project in Hannover is given.

2. EXPERIMENTS IN HORSTBERG

The Horstberg well is located some 80 km northeast of Hannover within the Nothern German Basin. It serves as a test well in a sparsely populated area. The target zones are the low permeability sandstone layers of the Middle Bunter in a depth range of 3640-3930 m and at a formation temperature of about 150°C. The stratigraphy of the target area, the well completion plan, and the temperature profile with depth are illustrated in Figure 1. Two particularities of the well must be noted. The target formations in the Middle Bunter are highly overpressurized. Under equilibrium conditions, the wellhead pressure amounts to 160 bar. Furthermore, the well completion offers the possibility to inject water in a shallow horizon (Calcareous Arenite) via the annulus (between 13 3/8" and 9 5/8" Casing). Produced high saline water can immediately be reinjected into this annulus.

The test site has been described in more detail elsewhere (e.g. Orzol et al., 2005).

2.1 Massive Hydrofracturing in the Detfurth Sandstone

In 2003, a massive hydrofracturing operation (waterfrac) was conducted in a perforated interval between 3787 – 3791 m in the Detfurth sandstone. About 20,000 m^3 of fresh water were injected at a flow rate of 50 l/s. From the pressure decline after fracturing, a fracture area of about 200,000 m^2 was derived, assuming a vertical fracture with much longer length than height (according to a PKN-model, see for instance: Economides & Nolte, 1989). A long-lasting linear flow regime was observed in successful production and injection tests. The pressure varied linearly with the square root of time, indicating a high (infinite) conductivity fracture with an area of more than 10,000 m^2, even at pressures below the formation pressure (Jung et al., 2005). Obviously, only a part of the originally created fracture remains highly conductive after fracturing. Based on geomechanical considerations, it is assumed that the fracturing in the sandstone layer remains highly conductive after pressure release, whereas the fractures closed in adjacent clay stones, as illustrated in Figure 2. However, the dimensions of this remaining fracture are still large compared to those of fractures that are typically created in more permeable rock by applying the proppant fracturing concept. This demonstrates that massive hydrofracturing without proppants can be a successful method of low permeability sedimentary rock stimulation.

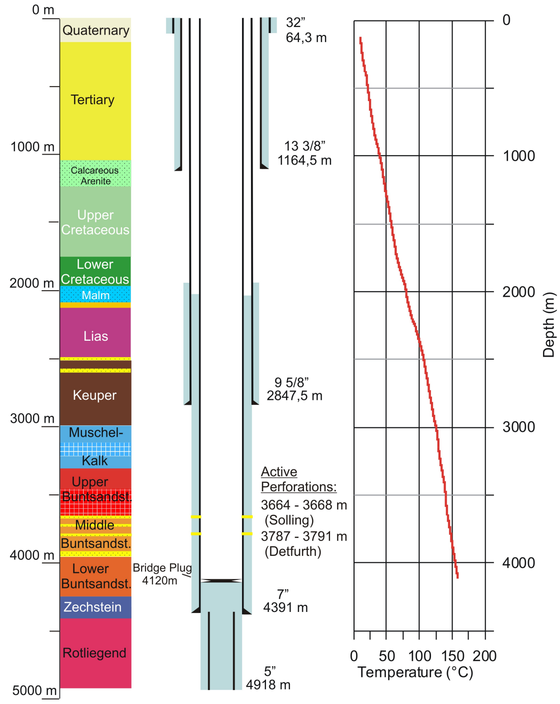

Figure 1: Stratigraphy, well completion and temperature profile of the well Horstberg.

The conceptual model of fracture propagation in the sandstone layer and in adjacent clay stones is illustrated in Figure 2.

The reason for the success of the hydrofracturing operation in Horstberg remains the subject of further laboratory investigations.

The fracture created in the Detfurth sandstone was the starting point for the testing of two different single well schemes, as outlined in the following sections.

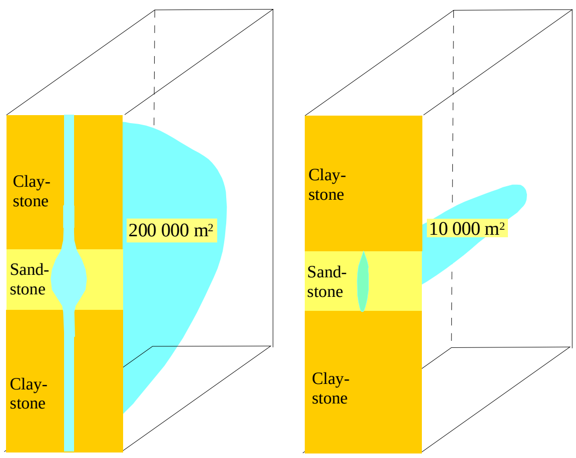

Figure 2: Schematic of the fracture shape/dimensions at the end of fracturing (left) and after pressure release (right).

2.2 Huff-Puff Concept

A highly permeable large fracture in a low permeability matrix offers the chance to produce heat using a cyclic injection and production scheme (huff-puff). Water is injected into the fracture and is then produced after a period of heating. The artificial fracture serves as a cyclic heat exchanger.

To test the feasibility of the concept, respective tests with daily and weekly cycles were performed. The planning and accomplishment of these tests (length of injection, shut-in and production period, fluid volumes injected and produced, etc.) obeyed the necessities of a practical operation.

For the weekly cycle, approximately 2,500 m³ of water were injected at the beginning of the weekend, and the well was then shut-in until early Monday morning. During the following five weekdays, water was produced from the fracture for 15 hours per day in daytime. Thus, the requirements of supplying heat to an office building were met: heat is provided on working days, whereas almost no heating is necessary at the weekends.

The pressure, flowrate and temperature histories during the weekly cycle test are shown in Figure 3. All injected water was successfully produced back during the working days by simply opening the well. The pressure curve during the injection period is dominated by fracture opening when the pressure was greater than the fracture pressure. In the following production periods, the pressure dropped by more than 100 bar and below the initial reservoir pressure. This pressure drop reflects the impact of a low permeability matrix and of partial fracture closing. However, starting from the second shut in period, the pressure curve is strongly correlated to formation linear flow with a unique set of parameters, indicating a highly conductive and mechanically stable fracture. As already mentioned above, a fracture area of more than 10,000 m^2 was derived from the fit shown in Figure 3.

During the production periods, the temperature at depth increased continuously, reflecting the fact that water entered the well from greater distances. At the end of production, the temperature reached the initial temperature of about 115°C (measured before injecting). The “low” temperature of 115°C compared to the undisturbed temperature of about 150°C is caused by the preceding fracturing and cooling. The observed temperature at the wellhead can differ from that at 3770 m depths by up to 25 K. This temperature difference reflects the heat loss along the borehole during production. Heat insulation tubing is therefore useful and often necessary to establish such a concept in practice.

The calculated thermal output in a weekly cycle scheme is shown in Figure 4. The numerical calculation was conducted based on a vertical fracture with a half length of 1000 m and a fracture height of 6 m. Further hydraulic and thermal properties of the fracture and matrix were derived via pressure transient analysis and fitting the downhole temperature curve. A constant reinjection temperature of 60°C was assumed. According to Figure 4, the mean thermal output during the production phases is approximately 1.3 MW_{th} at the beginning and decreases to 0.8 MW_{th} after 25 years of continuous cyclic operation. The average hydraulic pumping energy for injection is about 2-3 times smaller than the thermal energy gained in one cycle (in terms of primary energy).

The provided thermal power is smaller than the required heat demand of the Geozentrum Hannover. In principle, the thermal output can be enhanced by creating multiple fractures to increase water volume. If two fractures with similar areas and hydraulic properties could be created, the thermal output can exceed 2 MW_{th} for the entire period of 25 years, as indicated by the red line in Figure 4. The huff-puff scheme is a viable option to supply geothermal heat to the Geozentrum Hannover.

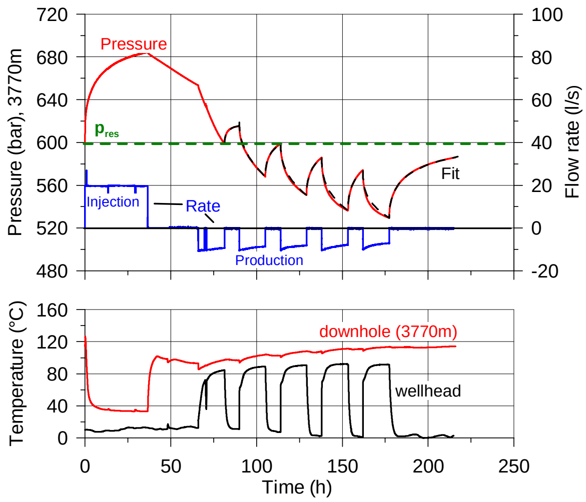

Figure 3: Downhole pressure, flow rate, and temperature (as well as wellhead temperature) during the weekly cycle (huff-puff). Positive flow rate indicates injection and negative flow rate indicates production. The green line in the upper picture depicts the undisturbed reservoir pressure (p_{res}).

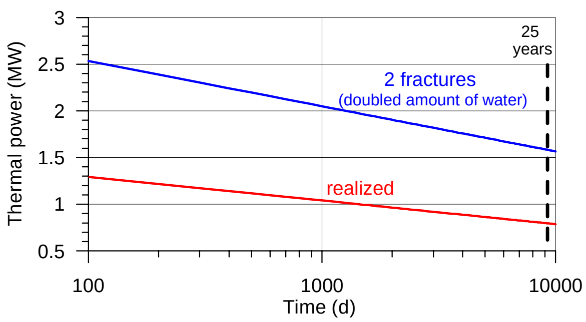

Figure 4: Numerical calculation of the thermal power gained in the weekly huff-puff test. The mean thermal output for the individual weekly tests is plotted versus time. The blue line reflects the thermal power assuming two identical fractures which do not interfere mutually.

2.3 Single well circulation

Hydraulic and thermal observations during the fracturing operation in the Detfurth formation indicated fracture propagation up to the Solling sandstone some 120 m above. This opened up the possibility of circulation between the Detfurth and Solling formations (Kehrer et al., 2007). A packer was installed at 3770 m along with tubing to separate both intervals within the wellbore, as shown in Figure 5. After a successful communication test between both horizons, a circulation experiment was conducted in 2004. Fresh water from shallow groundwater wells was injected into the tubing (Detfurth), and formation water was produced via the annulus (Solling). During circulation, high pressure pumps were used to specify an injection rate of 8 l/s. Production was realized by merely opening the annulus and reducing the pressure from 160 bar to about 100 bar. An overpressure of about 100 bar had to be maintained to allow for direct reinjection of the produced water into the Calcareous Arenite at about 1100 m depths.

A tracer response test during that experiment clearly revealed the communication between both horizons. On the other hand, a thermal short cut along the casing cementation, which might also explain a good hydraulic communication, could be excluded based on the significant tracer breakthrough volume of about 500 m^3.

For financial reasons, the circulation experiment lasted only for 14 days. During this short period, no stable circulation was achieved and more water was injected into the Detfurth than produced. Obviously, prolonged circulation is necessary to reach a balanced system between injection and production. Although the system was not balanced, the relation between energy output and energy input could be estimated. The gained thermal power during that test was in the range of 1.4 MW_{th} for a circulation rate of about 4 l/s and an assumed downhole production temperature of 150°C. Meanwhile, the energy input amounted to 0.4 MW (pumping energy in terms of primary energy). A long term circulation experiment was already planned for 2006, but because of financial and other reasons, a long term circulation test could not be conducted until now.

Numerical simulations indicate that at a circulation rate of 4 l/s, the calculated production temperature remains almost constant over the anticipated lifetime of 25 years. Consequently, the corresponding thermal power of 1.4 MW_{th} also remains constant. With a circulation of 8 l/s, the temperature decreases by about 15°C in 25 years, but the thermal power is higher than 2 MW_{th} even after 25 years of circulation.

The results of testing and numerical simulations demonstrate that one well circulation is a viable option for providing sufficient heat to an office complex like the Geozentrum.

However, one crucial barrier remains before this concept can be realized. In a single well circulation scheme, the wellbore itself acts as a heat exchanger between the tubing and annulus. If tubing without thermal insulation is deployed, heat will be transferred from the production side to the injection side along the wellbore, resulting in identical (low) production and injection temperatures at the surface. The single well circulation scheme is feasible for practice only if a very well insulated tubing (vacuum insulated tubing) is deployed. The high cost of vacuum insulated tubing prevented its application for test purposes in Horstberg.

3. DEMONSTRATION PROJECT IN HANNOVER (GEOZENTRUM)

Based on the good experience in Horstberg, it was decided to initiate the project in Hannover with the aim to supply geothermal heat to the Geozentrum. The 2006 – 2008 period was devoted to preparation work for this project (seismic campaign, inviting tenders, permissions, preparation of the drill site). In June 2009, the drilling operation began.

Similar to Horstberg, the target formation is the Middle Bunter at an expected depth range of 3700 – 4000 m. The well will be drilled in three sections and cased with 13 3/8", 9 5/8" and 7" casings. It is intended to deviate the lowest part of the well by an angle of approximately 25° in the direction of minimum horizontal stress. In this way, it is possible to achieve the best possible conditions for the creation of multiple fractures at different depths and avoid fracture propagation along the borehole axis.

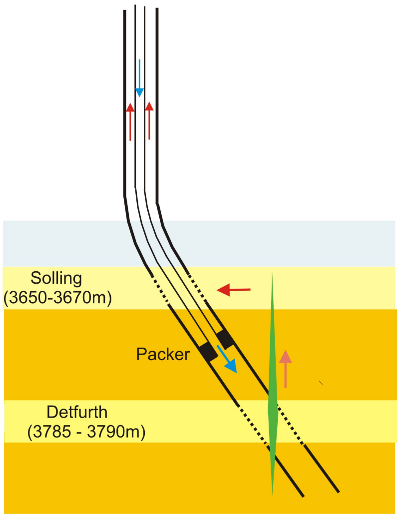

Figure 5: Circulation scheme between Detfurth (injection) and Solling (production). The green figure represents the artificial fracture.

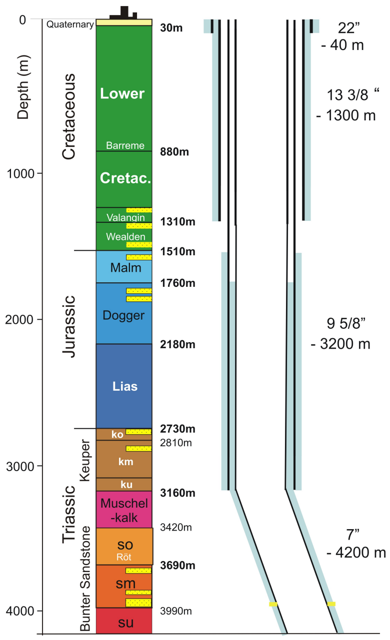

Figure 5: Scheme of the planned well in Hannover. The blue areas behind the casings symbolize the cemented parts.

For the drilling work, the newly developed InnovaRig will be applied. This rig was especially designed for scientific drilling and for operations in urban areas. The mast and hoist system is hydraulically driven. A special feature of the rig is the automatic pipe handling system, which minimizes the physical work on the platform. The InnovaRig guarantees low noise emissions. This is of special importance because the drill site is located about 50 m from a residential area. For additional noise protection, a sound insulation wall has been installed temporarily.

Figure 6: Photograph of the drill site in Hannover on June 12, 2009 during rigging up the InnovaRig

If the drilling operation succeeds within the expected time frame, the well will be finished in September 2009. Afterwards, preparations for massive hydraulic fracturing operations will follow, scheduled for 2010. Two or three fracturing operations will be performed in different layers to assure the best possible basis for either the single well circulation or the huff-puff concept. Additionally, the reliability of thermal insulated tubing will be evaluated as to determine the technical feasibility of a one well circulation scheme. If single well circulation does not appear to be feasible, a huff-puff scheme has to be realized. Different to the tests in Horstberg, a huff-puff scheme should then be performed on a longer time frame, preferably in yearly cycles. The advantages of a yearly cycle compared to a weekly cycle are at least twofold: the thermomechanical stress on the casing and cementation induced by alternating temperature and pressure is much lower, and the energy supply is more continuous. However, a yearly cycle requires two or more fractures with areas similar to or even larger than those in Horstberg.

A yearly cycle could be run as following:

1. Production of hot water from the deep well in winter (between October and March) and simultaneous injection of the produced and cooled water into a shallow storage well.
2. Production of the cold water from the shallow well and reinjection into the deep well in spring/summer (between April and June) with a significant higher injection rate than in step 1.
3. Recovery period (between July and September) to reheat the injected water in the deep well/fracture.

For the realization of a yearly cycle, a water volume of more than 100,000 m^3 must be stored while producing from the deep well. This large amount of water cannot be stored in a tank but only in the aquifer of a shallow well. For this reason, potential aquifer structures between 1200 and 1500 m depths will be evaluated during the drilling of the deep well. After the fracturing operation, it must be decided if another shallow well will be drilled as precondition for a yearly huff-puff cycle. It should be noted that such a shallow well is only for storage. Even if a second shallow well is drilled, it remains a one well concept.

The decision of which concept to employ (huff-puff or circulation) will be made following the massive fracturing operations in 2010 and the subsequent hydraulic tests. It is intended to build up a geothermal demonstration plant in 2011 or 2012.

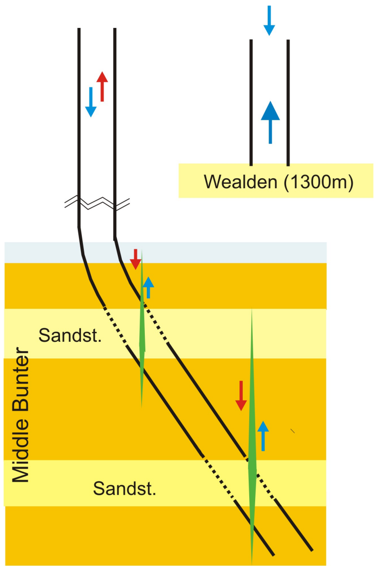

Figure 5: Scheme of a huff-puff concept with a shallow well as storage well – see explanation in the text.

4. CONCLUSION

The experiments performed in the Horstberg well revealed that large scale fractures can be created in sedimentary rock via the hydrofracturing concept developed in crystalline rock in hot dry rock projects.

A fracture area of about 10,000 m^2 at about 3800 m depth (Detfurth formation) remained highly conductive even at pressures below the reservoir pressure. Two single well concepts were tested to extract heat from the reservoir via this fracture. The first is the huff-puff scheme, which consists of a cold water injection period, a heating period, and a production period. The results of a cyclic test on a weekly basis showed that a thermal power of approximately 1 MW_{th} could be gained. A thermal power of about 2 MW_{th} is required for the envisaged geothermal demonstration plant in Hannover. Numerical simulations demonstrate that if two highly conductive fractures could be created with similar areas and similar hydraulic properties, the limit of 2 MW_{th} could be exceeded.

The other concept, single well circulation, was tested in Horstberg based on observed hydraulic communication between two sandstone layers via the fracture. This test yielded a thermal power of 1.4 MW_{th} at a flow rate of about 4 l/s. A twofold increase of the circulation rate is necessary to reach the limit of 2 MW_{th}, but it can be expected that a significantly higher flowrate than 4 l/s can be reached in a long term circulation experiment.

For the circulation scheme, the application of thermally insulated tubing (vacuum insulated) is necessary in order to avoid heat exchange between the simultaneous hot and cold water flow along the borehole. This is likely a serious challenge that must be overcome before such a concept can be applied in practice. However, thermal insulation tubing does not seem to be necessary for the alternative huff-puff scheme. Preferably, the huff-puff scheme should be realized in a yearly cycle to reduce the number of cycles and thereby reduce the alternate thermomechanical load on the casing and cementation.

The experiments in Horstberg demonstrated in principle that a single well concept is feasible for the heat supply of an office complex like the Geozentrum. Accordingly, it was decided to start the demonstration project in Hannover. The drilling operation for the planned well began in June 2009.

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