ENGINE COORDINATION ACTION

Summary of the Workshop 3
Stimulation of reservoir and induced microseismicity
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Introduction

Enhancing or engineering the reservoir Enhanced (or engineered) geothermal systems (EGS) are engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources. This includes all geothermal resources that are currently not in commercial production and require stimulation or enhancement. Mechanical and chemical stimulations are commonly used in order to enhance hydraulic properties of EGS systems. To the present day, the success of permeability improvement by massive hydraulic injections ("mechanical stimulation") is still a matter of trial and error and the success depends on the experiences made in geothermal and hydrocarbon reservoirs. Two main mechanisms for the success of permeability enhancement are to be considered: shear fracturing (or faulting) and jointing (tensile fracture). Both methods increase the pore pressure in the rock, however at different levels. A common view is that the shearing of natural fractures tends to produce dilation of the fracture walls and the opening of tubes at jogs in the fracture trace. The generation of microseismicity and the permanent nature of the transmissivity increases in both cases with different effects. The application of chemical acids generally improves conditions in the reservoir, however with largely varying success rates.

Creating artificial heat exchanger The concept of HDR-systems (ancient term, that are EGS without dominated natural water) foresaw the creation of an artificial heat exchanger at depth. The view nowadays is focused on the reservoir scale (i.e. a volume of several km³ around the wells located between 1.5 and 6 km depth). A heterogeneous natural geothermal reservoir is mostly dominated by a network of fracture clusters oriented close to the main horizontal stress direction. They are separated by distances of few hundred meters and crossing each other within distances of some kilometres forming a kind of 3D network of complex "aquifer" layers. The homogeneity of the geothermal water composition independent of sampling depth and the observed natural pressure distribution demonstrated that none of these clusters can be considered as being a totally closed system.

Improve inflow conditions In water bearing systems hydraulic fracture treatments have the goal either to bypass damaged permeability close to the well, or to create additional contact area between the reservoir and the well. While for the first goal the key is to maximize the fracture conductivity and thus the fracture width in the vicinity of the wellbore, the second goal requires large fractures, preferably connecting to an already existing network of natural fractures. Typically, such massive hydraulic fractures are placed in low-permeability reservoirs.

Stimulation techniques

Hydraulic fracturing – waterfrac The basic idea of hydraulic fracturing using the waterfrac technique is quite common –high rate injections pressurize the reservoir, leading to the creation of new fractures or to the enhancement of the permeability of pre-existing ones. The enhancement of permeability near the well is carried out to reduce the friction losses between the well and the formation. This is of particular importance for production wells, as experience has shown that the permeability of the injector will always improve during the circulation due to thermal contraction and the higher pressure. On the other hand improvement of permeability between the wells over larger distances (~1km) has always been a problem until recently, when this was successfully achieved at Soultz. The enhancement of permeability near a wellbore can be increased by applying high pressure for a short period. Pressure can reach above the minimum earths stress and this helps to shear all joints from critically aligned to the direction of maximum earths stress. Methods used for achieving this varies from using low viscosity fluid such as fresh water to high viscosity gels. *Hydraulic fracturing – proppant frac* The open hole hydraulic proppant fracture treatments can be applied successfully to deep sedimentary wells. Propped fractures are created and the inflow performance of the well can be enhanced. The successful placement of a propped hydraulic fracture depends critically on the quality of the design based on input data. Such data contain knowledge about the in-situ stresses, the reservoir permeability, the elastic parameters, and the fracture propagation criteria.

Geochemical stimulation Acid treatments have been successfully applied in many cases to increase or to recover geothermal wells production rates to commercial levels. Chemical stimulation techniques were originally developed to address similar problems in oil and gas production wells. The applicability of these stimulation techniques to a hot and fractured reservoir is less well known. High temperatures increase the acid-rock reaction rate. The development of Enhanced Geothermal Systems (EGS) depends on the creation of permeable and connected fractures. Acid stimulation jobs intend to clean (pre-existing) fractures by dissolving filling materials (secondary minerals or drilling mud) and mobilizing them for an efficient removal by flow transport. If, for example. a geothermal reservoir contains fractures partially filled with secondary carbonates (calcite and dolomite). In order to dissolve these carbonates and to enhance the productivity around the well, the borehole can be successfully treated with various amounts of hydrochloric acid. It is important to consider for chemical treatments, that the high reactivity prevents the penetration of acid in the far field between the wells. This high reactivity also involves the risk of creating wormholes, able to increase the porosity but not always the permeability of the fractured medium.

Thermal stimulation Intermittent cold water injection, with periods of thermal recovery in-between injection periods is one of the most common methods used for high-temperature well stimulation in Iceland. This method is aimed at causing cracking through thermal shocking.

Reservoir characterization during stimulation

Monitoring of injection-induced microseismicity as a method to image the stimulation effect During massive hydraulic stimulations large amounts of fluid are injected into the formation using drilled wells. Such water injections usually trigger considerable amounts of microseismic events that can be recorded by adequate seismic networks. The analysis of such data sets allows to estimate the orientation, i.e. dip and strike, of the (re-)activated fracture system. The deduced fracture orientation together with results from in-situ stress measurements are then used to describe the critical condition of fracture sliding. As a result one then can estimate the pore pressure at the location of the sliding fracture and at the time when the sliding (microseismicity) occurs. The generation of microseismicity can explained by the shearing of existing joints when the pore is increased until the normal stress goes to zero causing the joint to fail. Although the generation of microseismicity can only be associated with pressure increase in joints, there are ample observations that indicate that flow channels do exist within the seismic clouds.

Case studies

Soultz sous Forets The results observed during the past twenty years at Soultz demonstrated that “usual” hydraulic stimulation techniques when applied in such a hydrothermal / tectonic context can provide both real, but unfortunately limited, improvements of the well’s hydraulic performances and real, but fortunately up to now limited, microseismic nuisances. Seven major hydraulic stimulation tests performed at Soultz generated always large “microseismic clouds” but quite variable improvement of the wells hydraulic performances. The 5-km depth EGS reservoir of Soultz-sous-Forêts, France, has been developed using essentially fresh water and heavy brine injections. Thanks to these operations, connection could be achieved between two wells GPK2 and GPK3, the connection with the last well being problematic for the moment. The volume of injected acid in the first soft acidizing test on GPK4 had only an impact on the first 4 metres around the injection well. With these rather small acid amounts, the impact on the reservoir properties seems to be limited, although the porosity increases in the close vicinity of the wells due to carbonates dissolution.

Deep sediments (HC, Genesys, or Groß Schönebeck) Development of a technology to stimulate deep geothermal reservoirs in sedimentary basins is the purpose of installing the downhole geothermal laboratory in the former gas exploration well in Groß Schönebeck 3/90. The results of several reservoir treatments at site reflect the learning curve. These experiments are major steps towards developing a procedure to increase the thermal water productivity from a prior low permeability sedimentary reservoir. Open hole hydraulic proppant fracture treatments were successful applied at the geothermal research well Gross Schoenebeck 3/90. Propped fractures were created and the inflow performance of the well was enhanced. A still higher improvement was achieved using the waterfrac technique. For “engineering” this kind of reservoir type a method is recommended of massive waterfrac wth a proppant treatment at the end to ensure 1) connection to the reservoir by generating long fractures and increasing overall transmissibility 2) tie-back of generated fracture system to the well 3) sustaining fracture conductivity by proppant placement. Within the Genesys-experiments, an extensive test program including massive waterfrac tests and Geophysical fracture monitoring has been carried out in the last years. Waterfrac tests were performed using un-treated freshwater. Injection rates went up to 50 l/s at wellhead pressures of 330 bar during fracture propagation. Test analysis shows that the tensile fracture that was created covers an area on the order of 100.000 m² and has a vertical extension of approximately 200 m. Microseismicity was not observed in Groß Schönebeck, and only very few low magnitude events within the Genesys experiments.

Basaltic rocks in Iceland Stimulation of high-temperature production wells through cyclic cooling and thermal shocking/fracturing has proven to be effective for basaltic rocks, especially when the stimulation period can be extended for several weeks after the drill rig has been removed. Seismic monitoring should be more commonly applied during long stimulation- and injection operations, since it may provide highly valuable reservoir information. In addition, the application of reservoir monitoring, such as interference monitoring is recommended.

Lessons learned

Review HC-Stimulation and EGS-development and others implicate:

- More exchange between hydrocarbon industry and geothermal industry
- to consider the combination of geothermal experiments and CO2-sequestration
- the exchange with nuclear industry /hydrogeology - to extend the application of gel injection

Understanding Many parameters play a role in the failure mechanism that is expected:

- Fluid pressure development in the reservoirs, that depends on:
    - injection rate, time, and length
    - the setup of the test in the well
    - fluid type (water, heavy brine, gel of various viscosity, presence of proppants)
    - fluid temperature reservoir
- Stress field, that is different for each EGS site
    - Rock and fractures parameters, like cohesion and Mohr angle, may highly influence results obtained, and could be modified by the use of proppant agents or acid treatments
    - Shearing represents the relaxation of the natural shear stresses within the rock mass triggered by the weakening of the fracture by the elevated fluid pressure.
    - The pore pressure increase required to initiate shear failure on favourably oriented fractures is often very small.

This reflects the tendency for the Earth's crust to be close to failure, a state which is referred to as being critically stressed. As such, the vast majority of the mechanical work of permeability/porosity creation is done by the natural stresses. The stress state thus determines which fractures shear and thus has a major influence of the geometry of the stimulated volume and flow paths that develop therein. It follows that knowledge of the stress state is essential if the process of reservoir creation is to be understood and modelled, which is a step towards developing the means to control it. The confident determination of the complete stress tensor is at best difficult and often not practical. Fortunately, limited knowledge of the stress tensor suffices for reservoir engineering purposes, but complete knowledge is needed for modelling. Understanding the fracturing performance is helped by close monitoring. The pressure will always be recorded and a post-mortem analysis gives insight in the fracturing process. Monitoring during the fracturing process can also be done using tiltmeters and microseismic mapping.

To improve the basics it is recommended:

- to focus on understanding stimulation and to work on the predictability of stimulation
- to extend the knowledge about stress, artificial fractures, structures, fabrics (fracture propagation)
- to focus on understanding self propping
- to take proppant crushing into account
- to visualise stimulation in different geological environments
- to investigate scale dependence of fracture propagation
- and the validation of acidification treatments

The needs are:

- Long-term circulation tests
- Developping modelling tools (microseismicity)
- and technical tools (seismic anisotropy)
- to go again to shallow borehole experiments
- Geology 3D (impact of geology on success of EGS/HDR)

Public acceptance

Geothermal energy can be one of the future energy sources for base load power and heat provision. This way of environmental and sustainable energy supply is almost accepted. However, using the instruments for exploring, accessing (drilling into) and engineering the reservoir needs to be explained to the public to hold the acceptance on a high level. Especially explosion seismic (as done in Groß Schönebeck) and not least high rate stimulation (as done in Soultz and Basel) with recognisable seismological events must be prepared in a reliable publication management ensuring that every potential affected person is reached. In cases of violation of set thresholds the procedure most be stopped by the geothermal developper. This is much better than being stopped be local authorities.

References

Baujard C. & Kohl T. (eds.) 2006, Proceedings of the Engine Workshop 3 "Stimulation of Reservoir and Induced Microseismicity", 29 June - 1 July 2006, Zurich, Switzerland. ISBN 978-2-7159-0993-9. Orleans, BRGM Editions. Collection Actes/Proceedings. ISSN 1773-6161.