DEEPEGS Symposium

Extended abstracts

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DEEPEGS
GEOTHERMAL

Keynote lectures

 

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Overview of the risk and impact associated with EGS, application to EGS in the Rhine Graben

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When developing geothermal operations, it is important to be able to answer environmental concerns. Such concerns can be related to risks that can be avoided or managed and impacts that are unavoidable but that can be mitigated. To evaluate and lessen environmental concerns, both risks and impacts have to be considered. Based on literature review, a list of risk and impact that can occur along the lifetime of a geothermal operation has been established, regardless of their gravity and likeliness. Associated prevention and mitigation measures have then been studied along with monitoring measurements in order to evaluate their relevance and develop corresponding strategy to deal with them.

To study risks and impacts a whole chain of event must be evaluated. Indeed, the source of the risk (or impact) must be identified, the event causing it and the consequences to the environment have to be evaluated. It is only once this chain of event is clearly identified that prevention and mitigation measures can be assessed. As geothermal project are underground they are very dependent on geology. Through this paper, we will consider specific risks and impact related to EGS projects and operations in the Rhine graben (granitic basement), i.e. risks and impact associated with deep geothermal drilling and dealing with stimulation to improve injectivity. We will focus on a few subjects such as induced seismicity and identify how they are taken into account within a project, how they are monitored or prevented using good practice or regulation measures.

All industrial projects affect the environment. Geothermal energy is a renewable energy source (RES) and has some commonalities with other RES in term of risk and impact. Lifecycle analysis is a useful tool to evaluate these impacts. To conclude we will show some elements of comparisons (e.g. greenhouse gas emissions, material consumption or some economical aspects) to weigh geothermal project in the framework of RES.

This work was performed in the framework of the H2020 GEOENVI EU project which has received funding from the EU framework program for research and innovation under grant agreement No 818242.

An overview of geothermal reservoir enhancement results in the Rhine Graben during post-drilling well development operations and reservoir exploitation

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Two geothermal plants are in operation in the French part of the Upper Rhine Graben (in Soultz-sous-Forêts and Rittershoffen), and new wells have recently been drilled (for example in Illkirch, Strasbourg Region). All those geothermal sites target deep fractured crystalline basement in which natural brines are circulating. Many well development operations have been carried out in this region, with variable success rates, and operators now have a few years feedback on reservoir and well response to geothermal exploitation. First observations of operation data show that the well properties change over time and that the initially estimated well injectivity or productivity indexes are not always realistic. This change could be due to the well interference among each other's, or by mechanical and/or chemical processes due to the cooling of the injection area.

On Soultz-sous-Forêts site, three deep wells are used for the geothermal loop: the well GPK-2 is used as a producer while the wells GPK-3 and GPK-4 are used as injectors. The operation flowrate is around 30L/s. As the injectivity of GPK-4 is poor compared to the one of GPK-3, only a third of the flowrate is injected in GPK-4. The Soultz site has been commercially operated for more than 3 years. All the wells have been stimulated in the past. It is planned to improve the injectivity index of GPK-4 during exploitation by a chemical treatment.

On Rittershoffen site, the well GRT-1 is used as an injector and GRT-2 is used as a producer. The operation flowrate is around 80L/s. The Rittershoffen site has been commercially operated for more than 3 years. Only the injector has been stimulated due to poor initial productivity.

On Illkirch site, the well GIL-1 has been terminated mid-2019. An extensive chemical, hydraulic and thermal stimulation have been realized on this well but the results show that the final indexes are still lower than expected. Additional investigations and operations are scheduled on this well to better characterize the well and try to enhance the reservoir.

This communication gives an overview of well development results in these sites and the injectivity/productivity evolution of wells during operation is compared to initial estimated values derived from post drilling well tests. This work was performed in the framework of the H2020 DESTRESS EU project which has received funding from the EU framework program for research and innovation under grant agreement No 691728.

Engineering safe shear motions for the development of EGS reservoirs

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The classical hydraulic stimulation technology applied for the development of oil and gas reservoirs implies the injection of proppant in hydraulic fractures, but this technology requires some adaptation for high temperatures. An alternative technology that implies shear dilatancy has been proposed for the development of EGS reservoirs. The objective is to build up progressively the pore pressure in the rock mass so as to decrease the effective normal stress supported by critically preexisting oriented fractures. The lower the effective normal stress for which shear motion occurs, the larger the dilatancy associated with shear (Barton et al., 1985), and therefore the larger the permanent increase in hydraulic conductivity of the fracture at the end of stimulation

This concept has been tested in the mid-eighties, in particular at the granite test site of Le Mayet de Montagne (France) in a 250m to 840 depth range. Results demonstrated the efficiency of the technique but outlined the role of the minimum principal stress magnitude as a limiting factor for the efficiency of the technique.

Based on these results, two EGS reservoirs have been developed at the European Geothermal site at Soultz-sous-forêts, the first one at depths ranging from 2800 m to 3600 m, the second one at depths ranging from 4500 m to 5000 m. For both reservoirs it was possible, by increasing progressively the formation pressure, to create fresh shear zones that revealed to constitute key features for the development of these reservoirs.

But shear simulations generate micro seismic events, the magnitude of which may not be compatible with the surface use of land. Interestingly, results from Soultz outline the existence of large scale non-seismic shear motions and the presentation will discuss real time monitoring techniques for keeping non seismic the induced shear motions.

The politicization of the subsurface: from technical assumptions to social conflicts and political choices

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Session 1

Well performance prediction and assessment

Chairperson:

Emmanuel Gaucher

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Pierre DE MONTLEAU
Historical modelling and Forecast of a naturally fractured high enthalpy geothermal reservoir

Jia WANG
Estimating the Static Formation Temperature Using the Drilling and Logging Data of the RN-15/IDDP-2 Well in Iceland

Sturla SAETHER
Flow Performance of IDDP-2/DEEPEGS Well by calculating Local Injectivity Indexes for Different Reservoir Depths

Maziar GHOLAMI KORZANI
The Development of a Coupled Wellbore-Reservoir Simulator for Geothermal Applications

Mathieu DARNET
Advances for monitoring deep geothermal reservoir development with electromagnetic measurements

Hideo AOCHI
Concept of Traffic-Light-System (TLS) managing seismicity and injection for geothermal applications

Historical modelling and Forecast of a naturally fractured high enthalpy geothermal reservoir

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The Larderello-Travale field (Tuscany, Italy) is the oldest historical areas of geothermal exploration and exploitation in the world. Two reservoirs have been progressively investigated and exploited: i) the shallow reservoir, made up of Triassic-Jurassic carbonate-anhydrite formations and ii) the deep reservoir, composed by metamorphic/thermo-metamorphic rocks intruded by Quaternary granites bodies. It is a steam-dominated geothermal field. The current case study focuses on the deepest fractured reservoir in the southwestern area of the field, representing a fraction of the total production of the area.

A 3D static model has been built in Petrel based on a detailed geological reconstruction from outcrops, wells and seismic data. The areal dimension of the model is 16x14 km and its thickness is around 3000 m. Particular attention has been paid to natural fractures distribution performed by mean of image logs data and outcrops analogue analysis. Dynamic modeling has been performed with ECLIPSE 300 Thermal option. The history matching is performed on bottom hole pressure and bottom hole temperature, derived from the historical wellhead pressure and temperature measurements, while water production rate measurements serve as the control mode. In the Larderello-Travale area of the study, deepest reservoir development begun in the nineties and is characterized by temperatures of 250-350°C with an initial static pressure of around 70 bar. The area of the study is historically managed by 64 producers and 12 injectors; observation wells are also available for pressure monitoring.

The objective of the study is to give a better understanding of the production mechanism of a naturally fractured geothermal field by mean of fracture characterization and distribution. This calls for a detailed understanding of well productivity and interference between closed wells and groups of wells with the objective to support decision in terms of drilling and production management. Two examples are shown to illustrate the application.

Estimating the Static Formation Temperature Using the Drilling and Logging Data of the RN-15/IDDP-2 Well in Iceland

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The knowledge of the static formation temperature (SFT) around the RN-15/IDDP-2 well and the fluid loss along the well path is highly interesting information for geothermal exploration at the Reykjanes geothermal field (Iceland). Such information can be investigated by interpreting several temperature logs obtained during the drilling of the well. The temperature distribution within the wellbore is a response to the interplay of several factors such as wellbore flow conditions, fluid losses, well layout, heat transfer mechanics within the fluid as well as between the wellbore and the surrounding rock formation, etc. In this context, the numerical modeling method is a convenient and robust way to examine the influencing parameters/uncertainties in the interpretation of borehole temperature logging data. In the present study, firstly, the in-house developed wellbore simulator is introduced and validation of two thermal models presented. Secondly, synthetic scenarios are simulated to reflect the logging conditions during a warm-up period in May 2017, e.g. drill pipe-and-annulus wellbore geometry and continuous injection. One scope of the investigation is whether simple bottom-hole temperature correction methods are applicable to the logging data from boreholes which are under continuous cooling, due to the restriction in the temperature limit of the logging tools, to estimate the SFT. The other major purpose is to characterize the fluid loss percentage from the temperature logs using a simple method by computing the ratio of temperature gradient below and above the fluid loss point. Our results showed that applying simple temperature correction methods on the non-shut-in temperature data could lead to large errors in SFT estimates even at very low injection flow rates. Furthermore, the magnitude of the temperature gradient increase (or the temperature gradient ratio) depends on the flow rate, the percentage of fluid loss and the lateral heat transfer between the fluid and the rock formation. As indicated by this study, under low fluid losses (< 30%) or relatively higher flow rates (> 20 L/s), the impact of flow rate and the lateral heat transfer on the temperature gradient increase can be ignored. Finally, using the experience gained from the former synthetic case studies, we use, together, three temperature logs obtained under dynamic cooling conditions in the borehole to constrain the SFT until 2.5 km depth. The first results of this still on-going study will be discussed.

This work is part of the European Union's HORIZON 2020 research and innovation program under grant agreement No 690771.

Flow Performance of IDDP-2/DEEPEGS Well by calculating Local Injectivity Indexes for Different Reservoir Depths

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The goal of the Iceland Deep Drilling Project (IDDP) is to get appropriate understanding of supercritical reservoirs with ultra high temperatures (400-550 ℃). It is a huge potential of increasing the power output from one geothermal well in such reservoirs. There is always very interesting to know the prognosis for production potential and the energy content of hot producing wells in geothermal industry. This work will predict the required stimulation/heating of the IDDP-2/DEEPEGS well before start-up, and prognosis for the hot production of the well. Injectivity tests on cold wells is performed and will be used to get indications of the production potential. A significant amount of valuable data are collected in IDDP-2/DEEPEGS well. The injectivity index found by measurements provides an overall representation of the total well response and will normally not indicate zonal potential or contribution from various feed zones. This work uses existing data as temperature, pressure, and different flow rates during injectivity tests to point out local injectivity indexes in the different parts of the well. The fact that the pressure inside the well is different during the different injection rates are used in the prediction. The local injectivity indexes are used to predict the potential for hot production from the different production zones of the IDDP-2/DEEPEGS well. In addition, the data are used in the preparation for flowing the well. What heating/stimulation measures are required to ensure the IDDP-2/DEEPEGS well to start flowing.

The Development of a Coupled Wellbore-Reservoir Simulator for Geothermal Applications

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Boreholes under dynamic conditions are a highly non-linear and complexly coupled thermo-hydraulic system. Multiple parameters, for instance, temperature, pressure, specific heat, enthalpy, viscosity, flow regime, heat transfer, degassing, steam quality and salinity are inter connected. Production and injection often entail several engineering challenges and operational problems, within the boreholes but also up and down stream (reservoir - power plant - reservoir), which can be very diverse in their character. Finding solutions or working on process optimization prerequisite a profound understanding and a reliable numerical tool to quantify the processes. In this context, we developed a wellbore simulator implicitly solving transient fully-coupled non-isothermal two-phase pipe flow. Since the hydraulic and thermal connection to the reservoir is a crucial and critical point at the same time, we overcome the “reservoir-mimicking” boundaries (e.g. inflow performance relationships, productivity index, etc.) by integrating a real reservoir. Since the development of the tool is an ongoing process, we present the current state of the tool in this work and it’s most important capabilities, such as non-isothermal compressible two-phase pipe flow and the integration into a real reservoir. Future development efforts will concentrate mainly on the coupling to an appropriate module for the quantification of the aqueous chemistry and reactive multicomponent transport.

Advances for monitoring deep geothermal reservoir development with electromagnetic measurements

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Surface geophysical monitoring techniques are important tools for geothermal reservoir management as they provide unique information on the reservoir development away from boreholes. Electromagnetic (EM) methods are attractive monitoring tools as they allow to characterize the reservoir and hence potentially monitor changes related to fluid injection/production. Indeed, the electrical resistivity of reservoir rocks is highly dependent on the volume, temperature, chemistry and phase of the in-situ geothermal brine (e.g. liquid, vapor, supercritical). Passive EM techniques (e.g. magnetotellurics or MT) are traditionally used for geothermal exploration and a few recent studies have demonstrated its potential for monitoring reservoir development. One of the main challenges is though the presence of cultural noise and/or variability of the Earth magnetic field that can obfuscate the EM signals of interest.

In the framework of the H2020-DEEPEGS project, we have investigated the benefits and drawbacks of active EM surveying (Controlled-Source EM or CSEM) to tackle this challenge. In this paper, we will report the results of a time-lapse CSEM survey acquired in 2016 and 2017 over the Reykjanes geothermal field in Iceland before (baseline) and after (monitor) the thermal stimulation of the supercritical RN-15/IDDP-2 geothermal well. It showed that a high CSEM survey repeatability can be achieved with electric field measurements (within a few percent) but that time-lapse MT survey is a challenging task because of the high level of cultural noise in this industrialized environment. The analysis of changes in electric fields did not allow to identify any CSEM signal related to the thermal stimulation of the RN-15/IDDP-2 well. One possible explanation is the weakness of the time-lapse CSEM signal compared the achieved CSEM survey repeatability as a result of a limited resistivity change over a limited volume within the reservoir.

We also performed a calibration EM survey over the Vendenheim deep geothermal site in the Upper Rhine Graben to assess the feasibility of such an approach for monitoring reservoir development in deep sedimentary basins. It showed that despite the use of conventional CSEM transmitters (30 kW), data quality is poor due to high levels of electromagnetic noise and limits the applicability of the method. One possible solution is to deploy more powerful CSEM transmitter (> 100kW) and/or perform surface to borehole CSEM measurements. This would not only improve the data quality in noisy environments but also increase the spatial resolution of the technique.

Concept of Traffic-Light-System (TLS) managing seismicity and injection for geothermal applications

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Controlling and optimizing the well productivity with respect to the seismicity are major concerns in subsurface energy operation. A Traffic-Light-System (TLS) has been applied for monitoring the seismicity, namely for limiting the impacts on the vulnerability (infrastructure and perception). In the last years, a more flexible TLS (called "adaptive" or "dynamic") has been proposed to combine the observation and model to optimize the operation taking into account the possible seismicity evolution (e.g. Grigoli et al., https://doi.org/10.1002/2016RG000542 , 2017; Aochi et al., https://doi.org/10.1144/petgeo2016-065 , 2017). We attempt both mechanical and statistical approaches for describing the seismicity evolution due to the injection process. First, for a known case of the 2006 Basel (Switzerland) stimulation, we construct a conceptual seismicity model considering fluid diffusion and a friction law on a fault. The seismicity is a probabilistic process, such that the appearance is statistically discussed. We are able to demonstrate how the simulation is sensitive to certain parameters and how the dynamic TLS could have been applied during this injection. Next, also for a known example of the Soultz-sous-Forêt stimulation, we apply a statistical model, called Epidemic-Type Aftershock Sequence (ETAS). The seismicity evolution is a non-unique, non-linear problem, but the regression analyses clearly show the evolution from the injection period to post-injection. Our analyses tend to show that the seismicity has a strong triggering effect (earthquakes occur in cascade once they start) during the sequence.

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Session 2

Well design, drilling & completion

Chairperson:

Camille Maurel

BRGM, France

Vlasios LEONTIDIS

[Complete flow modelling of geothermal wells for different reservoir conditions]

Ólafur SVERRISSON

[Theistareykir Geothermal Power Plant – Successful Drilling Campaign]

Ómar SIGURDSSON

[IDDP2]

Frédéric GUINOT

[Injecting more Engineering in the E of EGS]

Complete flow modelling of geothermal wells for different reservoir conditions

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The geothermal energy is exploited in numerous areas around the earth at depths ranging from some tens of meters up to a few kilometres, with a produced fluid temperature between ~30°C (low enthalpy) and ~500°C(high enthalpy), covering the whole range of the phase diagram since the exploitation from supercritical geothermal resources is being considered for the next generation of energy production systems. In all above cases, several technical challenges are being raised which required to be handled in the exploration phase to ensure the efficient delivering of clean energy. The extend of these issues and their solution depends strongly on the reservoir conditions, the fluid chemistry with sometimes considerable concentrations of minerals and dissolved gases, and the total geothermal flow rate. The correct design of the production and the injection wells, which are the link between the energy source and the energy production, is crucial, making the accurate modelling of the fluid and heat flow in the wells a key issue.

Within the GECO H2020 project ("Geothermal Emission COntrol"), aiming at producing high enthalpy geothermal energy with zero greenhouse and acid gases emission, a completion configuration is proposed ensuring the simultaneous re-injection of non-condensable gases and condensed water in the same well, based on a fully-coupled thermal multiphase flow model. This numerical tool models the one dimensional non-isothermal steady state single- and multi-phase flow in wells with deviated trajectories. An advanced thermodynamic model is integrated for the calculations of all physical properties as a function of temperature and pressure. Additionally, the one dimensional radial heat transfer with the host rock is modelled considering the heat capacity of all layers. The model has been designed to cover both the production and the reinjection wells.

Severe technical problems can raise due to scale deposition and corrosion in wells. To address these risks, the already developed model will be enhanced for assessing the deposition and corrosion trends along the well based on the flowing conditions (pressure, temperature, flow rate), the chemistry (components such as CO_2, H_2S, anions, cations) and the fluid physical state (supercritical, gas, liquid).

Þeistareykir Geothermal Power Plant – Successful Drilling Campaign

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The 90 MWe Theistareykir is the latest geothermal powerplant in Iceland, commissioned in December 2017. The plant is powered by 14 production wells, currently yielding around 105 MWe of steam. The enthalpy of the geothermal resource is in the range of water dominated up to almost dry steam (1200-2700 kJ/kg). The drilling in the most productive part of the field proved to be highly challenging due to overpressure in the upper most 300 m.

In the year 2000, four municipalities in Northeast Iceland formed a special company, Theistareykir Ltd. The main goal was to harness the Theistareykir geothermal resource by generating electricity to attract power intensive industry into the area and hence create valuable jobs. The first two exploration wells were drilled in 2002 and 2003. In 2005 Landsvirkjun bought one-third share in the company and in the following years Landsvirkjun increased its share by funding further exploration drilling before buying all remaining shares in the company in 2010. In 2014, a decision was made to build a 90 MWe geothermal power plant at Theistareykir. At that time, in total nine exploration wells had been drilled in the area. Seven of them could provide steam to produce about 57 MWe.

Drilling works for 7-10 wells in Theistareykir and Krafla geothermal areas was tendered in 2015 in an open tender. Four international drilling contractors participated and submitted highly competitive bids and a contract was signed with the Iceland Drilling Company, which provided the lowest bid.

The drilling campaign started in May 2016 and was completed in August 2017. A total of eight wells were drilled to depth from 2200 m to 2700 m, all of them were deviated. Number of challenges had to be met during the drilling and the first well had to be abandoned after a blowout caused by flow between feed zones at 154 and 184 m depth. To prevent further failures, the design of the wells in the areas expected to be overpressured was modified. In continuation all wells were successfully completed.

The presentation describes the challenges met during the drilling campaign and how they were met to ensure successful results.

Stimulation activity in the deep well RN-15/IDDP-2 at Reykjanes, Iceland

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Injecting more Engineering in the E of EGS

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To make deep geothermal a viable industrial proposition, the technical and economic risks must be minimized. Unlike oil and gas where the risks and failures are immensely offset by the cash flow generated by successful projects, geothermal projects with similar risks compete with other energy sources in a heavily regulated market and never enjoy similar returns. The economic acceptability of geothermal power generation requires low risk drilling and completion technologies that would work under many different geological conditions. That is the ambition of EGS developers.

When wells are drilled into a petro-thermal formation, there is normally no clear circulation path between these wells (injectors and producers) and when this path exists, the transmissivity is so low that no economical project is possible. Then, engineered geothermal systems (EGS) rely on reservoir stimulation to create downhole heat exchangers where the energy can be harvested. EGS is then a form of reservoir creation rather than a conventional stimulation technique.

A successful EGS requires that enough rock surface is contacted by the geothermal fluid, and that the fluid runs smoothly through a sufficient rock mass. When the system brings enough energy to surface, a positive net present value (NPV) is generated to the satisfaction of the investors. However, the success of the stimulation and creation of the EGS relies heavily on a proper well design and an appropriate completion system.

The success of oil and gas “unconventional” production is essentially due to the use of specific completion technologies, that allow efficient stimulation of barely permeable formations. Multi-stage stimulation could also be used to reliably construct EGS. However, the existing completion tools are not readily applicable to EGS and some developments are still needed to fit the geothermal needs.

Session 3

Enhancement technologies and methods

Chairperson:

Julie Maury

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Morgan LE LOUS
Geothermal well testing and stimulation: a complete methodology applied to Vendenheim well VDH-GT2 (Alsace, France)

Barnaby FRYER
Temperature-induced stress preconditioning

Van Hieu TRAN
Numerical Modelling of Thermal Stimulation in Enhanced Geothermal Systems (EGS)

Théophile GUILLON
Reactivation of a fault zone internal structure in response to hydraulic stimulation

Antoine ARMANDINE LES LANDES
Hydrothermal simulation in a fault zone: Impact and efficiency of different stimulation methods

Cyprien SOULAINE
Multi-scale modelling of coupled hydrogeochemical processes

Pierre DURST
From Fenton Hill to Vendenheim, 40 years of chemical stimulation in Enhanced Geothermal Systems

Geothermal well testing and stimulation: a complete methodology applied to Vendenheim well VDH-GT2 (Alsace, France)

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In the Upper Rhine Graben (Alsace region, North-Eastern France), geothermal development takes place since decades thanks to the expertise developed for the Soultz-sous-Forêts power production plant (Baria et al., 1999) and the most recent Rittershoffen heat plant (Baujard et al., 2017). With the Illkirch project (Baujard et al., 2018), the Vendenheim project (Le Lous et al., 2019) is part of the recent development in Northern Alsace willing to combine power and heat production for Strasbourg and its urban community.

Within the framework of the research project DEEPEGS, Vendenheim wells were drilled by the operator Fonroche Geothermie for targeting local normal faults located at the interface between the sedimentary formations and the Paleozoic crystalline basement. Used for reinjection of the geothermal brine after energy recovery, well VDH-GT2 reaches a depth of 5308 m MD (4426 m TVD).

To assess the initial injectivity index of the well, a step-rate injection was performed up to a maximum pressure of 100 bar at surface conditions. A complete methodology was designed to enhance the hydrogeological properties of the near-wellbore subsurface fractured-network. Enhancement of well VDH-GT2 was achieved through chemical, hydraulic and thermal stimulations that were conducted alternatively for weeks. To increase well's hydraulic performances to a commercial level, stimulations range from very short high-rate injection to long low-rate injection.

Testing of the injection well VDH-GT2 was achieved to validate its commercial viability as part of a well-doublet operation. Pressure-temperature log over depth as well as production test with airlift and the subsequent monitoring of the build-up helped to derive the main well comportment (i.e. theoretical well model, pay zone, skin), reservoir parameters (i.e. transmissibility,), along with reservoir boundary conditions (i.e. shape, type, distance). Such estimates consequently provide key information for future plant development.

This research is carried out in the DEEPEGS project handled by Fonroche Géothermie.

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Temperature-induced stress preconditioning

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A methodology is suggested for stimulating Enhanced Geothermal System (EGS) reservoirs in shear such that there is a reduced chance of incurring a seismic event of large magnitude. The methodology is developed here for a reverse faulting stress regime. The reservoir here is assumed to be a crystalline reservoir with limited matrix permeability. The flow is therefore primarily assumed to occur in the fractures; the primary stimulation mechanism is assumed to be shear failure.

The methodology involves an initial phase of temperature-induced stress preconditioning. In essence, this stress preconditioning phase is a period where the unstimulated reservoir is cooled via the injection of cold fluid. In order for this methodology to work, the reservoir therefore requires at least some initial permeability. The cooling period occurs over an extended period of time, for example 1 year. The cooling results in a reduction in stress, primarily the two horizontal stresses and especially in horizontally extensive reservoirs. The reduction in horizontal stress results in a reduction of differential stress in this stress regime, moving any optimally oriented planes of weakness away from failure according to Coulomb faulting theory. After this preconditioning phase, the reservoir is stimulated through high pressure injection. Since our focus lies on the ability to develop a reservoir by reservoir scale stimulation, we disregard for the time being the lower energy conversion efficiency due to the cooling of the reservoir.

The reason that this stimulation methodology is expected to result in a lower chance of a large event is seen through the connection seen between Gutenberg-Richter b-value and differential stress (e.g., Scholz, 1968; Amitrano, 2003; Schorlemmer et al., 2005). The low differential stress at shear failure in this methodology is therefore expected to result in a lower chance of incurring a large magnitude event, where the chance reduction scales with the amount of temperature reduction.

The pre-stimulation injection rates required to incur the temperature changes required in this methodology are on par with the pre-stimulation rates seen, for example, at Soultz-sous-Forêts (Evans et al., 2005). However, in cases of exceptionally low permeability this methodology may not be realistic on a reasonable time scale. Variations of this methodology can be readily developed for both normal and strike slip faulting stress regimes.

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DEEPEGS GEOTHERMAL

Numerical Modelling of Thermal Stimulation in Enhanced Geothermal Systems (EGS): Application to the Vendenheim Demonstrator in the DEEPEGS Project

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EGS (Enhanced Geothermal System) is a technology to create a man-made reservoir where there is hot rock but low natural permeability. The cold fluid is injected under carefully control which allows to reo-pen the existing fracture gain due to the increase of permeability in the hot rock. The DEEPEGS project aims at demonstrating the feasibility of EGS in different geological contexts, in order to deliver new innovative solutions and models for wider deployments of EGS. The assessment of the well injectivity gain by stimulation methods is one of the ongoing challenges that need to be addressed. In this paper, we propose to assess the efficiency of the thermal stimulation by numerical modelling with a “micro-macro” Discrete Element Method (DEM) approach (PFC ©Itasca) in the Vendenheim French demonstrator.

In this demonstrator, the in-situ stress field varies from normal regime to strike-slip regime. The main horizontal stress is roughly oriented NW–SE, with local variations from N130°E to N180°E. The temperature measured at 5393m of the depth was around 200°C. The data from the first well in Vendenheim shows the presence of a quartz vein partially sealing the discontinuity (Peter-Borie and al., 2019). Know that the quartz is badly suffered under thermal stress, a parametric study on the influence of temperature is proposed by applying the strike-slip regime and without overpressure. The temperature difference between the rock mass and the fluid is 150°C. The numerical results shows the propagation of coalescing cracks from the pre-existing discontinuity gain due to thermal stimulation. These coalescing cracks contributes to the permeability increase in the rock matrix that can be estimated by the Poiseuille law (Tran VH and al., 2018). In addition, the development of coalescing cracks shows the fractures net-work is transferred into a hydraulic model with Discrete Fracture Network approach by the translation of the thermal cracking into the increase permeability (Armandine les Landes et al., 2019).

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Reactivation of a fault zone internal structure in response to hydraulic stimulation

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Hydraulic stimulation has been widely used as a primary method to increase well injectivity and/or productivity in the context of Enhanced Geothermal Systems. In most cases, the aim was to reactivate preexisting fault zones (hydrothermal reservoirs), although some cases exist where stimulation was intended to fracture the rock matrix (petrothermal reservoirs). By reactivating natural fault zones, hydraulic stimulation is known to come with the major drawback of inducing seismicity. In France, the strict regulation on induced seismicity (maximum local magnitude of 2) relayed this technique to a secondary method in stimulation scenarios. Still, “soft” hydraulic stimulation (wellhead pressure lower than 10 bars) can be used as an efficient kick-off for subsequent stimulations (chemical or thermal). Especially in so called “fault zone reservoir” where a major fault zone is targeted for hosting the heat exchanger. With widths of hundreds of meters, such fault zones contain a complex fractured internal structure that should, in principle, favor the heat exchanges with the rock matrix. Despite its low injection pressures, soft stimulation is expected to widely affect the overall equivalent permeability by means of flow paths ramifications and associated hydromechanical 3D mechanical interactions. In this paper, we propose to numerically study this phenomenon considering the specificity of such a geothermal target in terms of geometry, tectonic context and well trajectory. The first yet critical step is to conceptualize the deeply complex reality of the fault zone considering the partial data and knowledge available. We present the choices that have been made in order to depict a realistic model while fitting the numerical requirements (the distinct element method was used to explicitly account for the discontinuities). We then show the associated physical model considered for addressing the hydromechanical response of the system. In the end, we discuss the main results of the study. The irreversible openings are shown to unequally affect the main compartments of the fault zone and highlight the necessity to properly conceptualize the internal structure (permeable / impermeable compartments). The final distribution is also greatly affected by the 3D interactions inside the fault zone, with some stimulated areas not in the surroundings of the well injection points. To finish with, we qualitatively explore the impact of the infills nature by testing two sets of joint mechanical parameters depicting, on the one hand, a rigid behavior (sealed fracture) and , on the other hand, a softer behavior (brecchified argillaceous material).

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Hydrothermal simulation in a fault zone: Impact and efficiency of different stimulation methods

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We propose a method to assess the injectivity gain through implementation of different stimulation scenarios coupled with multidrain architectures. A same reservoir model is considered as a base for several predictive numerical simulations. As a first step, for each stimulation method (thermal stimulation, hydraulic stimulation and multidrain architecture), we run simulations with adapted numerical tool taking into account the main involved physical processes. In a second step, a workflow of stimulation methods is run for investigating the "best" scenario.

This approach is tested in a fault zone context, located in the granitic basement of the Upper Rhine Graben (Eastern France), at around 4400m TVD (True Vertical Depth) where the temperature is estimated around 200°C. Based on the drilling data recorded and structural hypothesis hinging on a multiscale approach, a conceptual model of the faulted geothermal reservoir is established. Then, a hydrothermal model of the fault zone is built using the ComPASS code, which enables the implementation of 2D discrete fracture or fault network into a 3D matrix (so-called hybrid-dimensional model). The current code is able to handle compositional multiphase Darcy flows, coupled to the conductive and convective transfers of energy (Lopez et al., 2018). The hydrothermal model is used to simulate an injection test setting the initial reference injectivity result for the well.

Then, we study the impact of different technologies using a one-way coupling logic: the adapted numerical models are run, and their results are incorporated into the hydrothermal model before launching the injection test. We propose to study the impact of three technologies: a two-legs well geometry, a hydromechanical (HM) stimulation, and a thermomechanical stimulation. The two-legs model is not strictly speaking a one-way coupling, but rather modifies the number and positions of injection points in the hydrothermal model. The HM model simulates the effect of fault reactivation (soft-stimulation Blaisonneau et al., 2020) and modifies the initial permeability distribution among the fault network. The thermomechanical (TM) model simulates the thermal fracturing potential of the sealing of the fractures (Peter-Borie et al., 2019 or Tran et al., 2019), and modifies the initial permeability distribution around the well and in the surrounding the fractures.

The different models are studied as standalones and are sequenced in various orders to explore a few scenarios. For each scenario, the injectivity can be compared with the initial model and the relative efficiency of each stimulation method within the sequence can be assessed. For this specific case, it appears that the different methods investigated (HM, TM, two-branches architecture) lead to the same order of magnitude in terms of injectivity improvement. The injectivity for each method considered separately is multiplied by a factor comprised between 1.2 and 1.5. The combination of methods (HM + two-legs) enables further improvement of injectivity, with multiplication factor around 2.6. Nevertheless, these results are very dependent from the choice of parameters and should thus be considered cautiously. As a conclusion, the import of constraints provided by other numerical codes into this unique hydrothermal model offers a way to test different scenarios of stimulation in order to identify the most appropriate solution.

This work was carried out in the framework of the project DEEPEGS. This project is funded under the call H2020-LCE-2015-2. Grant agreement n°690771.

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DEEPEGS
GEOTHERMAL

Multi-scale modeling of coupled hydro-geochemical processes in porous and fractured reservoirs

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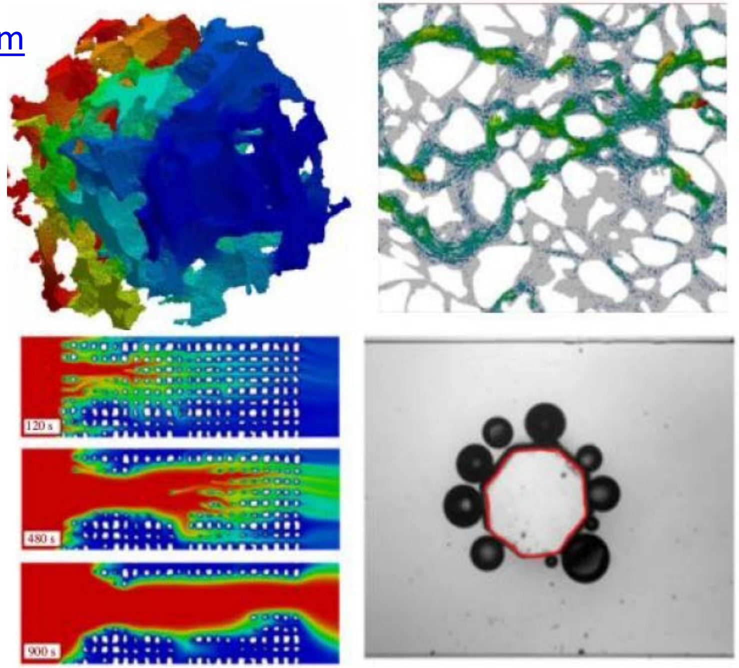
Effective use of the Earth subsurface for resources and energy applications requires very good control of time- and space-dependent fluid flow regimes. Such applications include the exploitation of groundwater reservoirs, the injection and sequestration of CO_2 into deep saline aquifers, the storage of nuclear waste repositories, the development of geothermal energy, and the oil and gas recovery. Subsurface acidizing can lead to a reorganization of the pore-space through mineral dissolution and precipitation. These modifications of the rocks topology locally change the streamlines and, therefore, the hydraulic properties of rocks. The feedbacks between flow and geochemical reactions are complex and highly coupled. A good understanding of these non-linear phenomena is crucial to assess the long-term effectiveness and the environmental impact of such processes. Pore-scale analysis of the involved physico-chemical processes is the elementary step in a modeling strategy involving a cascade of scales nested within each other. To date, the state-of-the-art porescale simulators still suffer from severe limitations: (i) geochemistry is oversimplified, (ii) multiphase flow and geochemical reactions are never treated concomitantly, (iii) the scales considered does not reach the size of a Representative Elementary Volume, which does not allow for realistic micro-scale descriptions of transport in fractured media. Using devoted numerical modeling based on the microcontinuum approach[1,2,3], and microfluidic experiments[2], we highlighted and characterized several regimes of dissolution instability at the scale of individual grains and fracture. We also demonstrated that the presence of a gas phase changes the stability diagrams[4]. These results, upscaled to a continuum-scale formulation, inform the hydraulic and transport properties, and shed new light on the differences observed between lab and field measurements.



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From Fenton Hill to Vendenheim, 40 years of chemical stimulation in Enhanced Geothermal Systems

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From the beginning of HDR exploration in Fenton Hill in 1976 to the current EGS projects, chemical stimulation has been used for reservoir permeability enhancement. A summary of results from nine projects around has be completed[1, 2, 3, 4]. These results highlight that acidification methods from oil and gas industry has to be adapted for deep geothermal reservoirs.

- First, the temperature researched for geothermal exploitation is usually significantly higher than in oil and gas reservoirs, modifying chemical interactions between the treatment produces and the formation minerals.

- Second, the objective of reservoir development for geothermal exploitation is focused more on increasing the circulation of fluids over long distances than on extracting fluid from the matrix.

The results from field operations and lab experiments[5] were used for geochemical modelling to test scenarios of acidification in the context of the Vendenheim project in order to optimize chemical stimulation and to see how to articulate it with hydraulic and thermal stimulations.

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DEEPEGS GEOTHERMAL

Posters

P. Blanc

Geothermal drilling: Geochemical assessment of cement durability in the supercritical domain

H. Aochi

Statistical analysis of microseismicity during the stimulations at Soultz-sous-Forêts (France) EGS site.

J. Wang

Estimating the Static Formation Temperature Using the Drilling and Logging Data of the RN-15/IDDP-2 Well in Iceland

Geothermal drilling: Geochemical assessment of cement durability in the supercritical domain

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In the framework of high enthalpy geothermal operations, it is necessary to assess the durability of cements under high thermal gradient, especially regarding their mineralogical evolution and possible alteration. Geochemical calculations can be used for the purpose, provided an adaptation of the thermodynamic database for temperatures above 300°C. This starts by using the HKF model[1,2], which computes standard molal thermodynamic properties (heat capacity, volume, Gibbs free energy) for aqueous species at temperature and pressure in the supercritical domain. In some cases, parameters used in the model were determined by Sverjensky et al[3] correlation. Selection for cement minerals is also improved, consistently with the IDDP1 (Iceland Deep Drilling Project) well cement samples analyses and the results of lab experiments.

Finally, a tool is built allowing the calculation of a PHREEQC-V2[4] and GWB[5] database between 0 to 600°C along specific P-T profiles. The geochemical calculations with the upgraded database allows predicting potential cement evolutions during temperature and pressure changes in term of mineral phase transitions and their effect on volume and water content.

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DEEPEGS
GEOTHERMAL

Geothermal drilling: Geochemical assessment of cement durability in the supercritical domain

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Monitoring the microseismicity according to the fluid injection is necessary for assessing better the reservoir behavior at Enhanced Geothermal System or other subsurface exploitation. Mechanical modeling is helpful, but it is still difficult to consider all the aspects due to the limits of numerical frameworks and poor knowledge of certain model parameters. We then alternatively aim to analyze the statistically microseismicity to follow the temporal evolution linked to the injection operation. Earthquakes occur due to any loading forces (regional stress accumulation and/or pore pressure increase). On the other hand, once an earthquake occurs, it redistributes the stress in the surrounding and leads to other earthquakes (called 'aftershock'). We need to distinguish them. In seismology, statistical models have been developed and successfully applied in various seismicity in the world, including Epidemic-Type Aftershock Sequence (ETAS) model (e.g. Ogata, Ann. Inst. Statist. Math, 50:379-402, 1998). We apply the ETAS model on the microseismicity for the 1993 and 2000 stimulation experiments at Soultz-sous-Forêts EGS site (Alsace, France). Thousands earthquakes in the published catalogue (Data Center for Deep Geothermal Energy; https://cdgp.u-strasbg.fr/) allow us to analyze the temporal change of the seismicity rate. Among the five model parameters in ETAS model, some parameters are too sensitive to decide reliably, however our analyses show an important launch of the seismicity rate at the beginning and a gradual decrease with time. This is qualitatively consistent with the observations.

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