FRAUNHOFER RESEARCH INSTITUTION FOR ENERGY INFRASTRUCTURES AND GEOTHERMAL SYSTEMS, IEG

ZODREX

ZONAL ISOLATION, DRILLING AND EXPLOITATION OF EGS PROJECTS

170160-44011

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Identification of Project

General Information

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Introduction

Enhanced or Engineered Geothermal Systems (EGS), targeting the exploitation of deep geothermal and petrothermal resources through closed loop or open hole type heat exchangers through the heat bearing formation, convey thermal energy stored in non-water-bearing geological formations through reservoir fluids or working mediums from subsurface to surface. These deep geothermal resources provide a rather viable opportunity to meet and satisfy base load energy needs. EGS systems may supply both, heating and electricity generation and thus, differ from other renewable energy sources like wind and solar as they embrace small geographic and environmental footprint, virtually inexhaustible, universally availability, and 24/7 weather / season-independent reliability. Processes and methods of deep geothermal exploitation do rely partly on techniques applied in the immense global Upstream and Exploration and Production (E&P) sector of the Oil and Gas (O&G) industry. Knowhow and some parts of technology of this industry is already partly been utilized and transferred to foster economic exploitation of deep geothermal resources. Moreover, a vibrant and prospective deep geothermal energy industry may function as a subsequent and final destination for the E&P industry through employing readily available technology and maintaining proven workplaces, all to achieve a more sustainable future both environmentally and economically. That said, some prevailing differences between the geothermal and hydrocarbon E&P sector must still be addressed in the future: higher temperatures, typically hard rocks and usually deeper, and rather impermeable reservoirs are part of these challenges. The latter two aspects are having been targeted and addressed intensively by the ZoDrEx consortium, particularly, through the contributions of Fraunhofer IEG to the research project. In that regard, novel percussion drilling technologies, permeability enhancing stimulation treatments and small caliber milling / drilling mechanisms are being researched and presented in the following. [1–4]

WP1 Task 1.1

Description

Demonstrate feasibility of fluid-driven, percussion DTH hammer drilling in highly deviated / near horizontal wellbores. Near horizontal drilling is an effective way to better connect vertical wellbores to the reservoir. Thus, demonstration of the capabilities of percussion DTH hammer drilling in highly deviated / horizontal wellbores without extra deviation control is a mandatory task. Analyze the trajectory of such a wellbore with special emphasis on possible inclination or "drop" with increasing wellbore "depth" or length. Compare Percussion DTH drilling to rotary drilling in highly deviated / horizontal wells. Does percussion drilling result in less deviation than rotary drilling? Differentiate the impacts of the rock breaking process itself and the assembly of the BHA / drill string components.	IEG GES

Overview

Directional Drilling and Wellbore Deviation

Directional Drilling refers to the intentional drilling of a wellbore along a selected path to a predefined objective like a rock formation. In that regard, deviation control means taking action to adhere to the path with drilling. Both path and objective are termed wellbore trajectory and target, respectively. A proper description of the trajectory is possible through only two angles in three-dimensional space. Deviation into the direction plane X and the inclination plane Y are accomplished through the respective eponymous angles. [5]

Along a wellbore trajectory, deviation is initiated at the so-called kickoff point (KOP). The severity of the conducted deviation is classified amongst others through the inclination angle and its rate change. As a rule of thumb, the extent of the contact between wellbore and reservoir is roughly proportional to fluid production. This preferentializes boosting of contact between both system entities through extensive HD and hence high inclination angles. Horizontal boreholes represent the optimized and highest level of this approach as HD is maximized, rendering their application ever more important. This leads to yet another classification method of deviated wellbores: the necessary turn radius to achieve a fully horizontal setting from an initial vertical starting position. Conventional deviation in the O&G industry is long and medium radius. On the other hand, short radius refers amongst others to radial jet drilling (RJD). Equipment variations and limitations respectively impede and prohibit drilling in-between long, medium and short radius setups. [6]

Percussion Drilling Technology

In the past, percussion drilling technologies have proven to significantly increase rate of penetration (ROP), a measure assessing the speed of the drilling. As ROP is the crucial measure for the determination of operational success or failure, much focus lies on improving and maximizing ROP. Due to the percussive action on the rock surface, so-called down-the-hole drill (DTH) technology allows for especially high ROP's in hard formations like the Saint-Gotthard granite, rock delineating reservoir characteristics suited for geothermal exploitation [7]; conventional rotary drilling employs either point load crushing (Tri-Cone) or sole shear cutting (PDC) action on the rock surface resulting in lower ROP in hard rock. This is the reason for the investigation of percussion hammer technology for application in geothermal wellbores. [5]

DTH Percussion Drilling

Fraunhofer IEG and its predecessor institute GZB have a long-standing history of R&D work and applied projects using DTH type percussion drilling technologies, with ROPs ranging well up to 1 m/min for shallow and slightly deviated wellbores down to 500 m depth. General trends for liquid DTH percussion drilling were demonstrated and can be summarized as follows: ROP decreases only slightly with increasing depth, while required mud circulation times rise proportionally with depth as the distance between bottom hole and surface increases; so far only water could be used as a carrier fluid (drill "mud") for cuttings evacuation. ROP typically refers to bit turning on bottom and breaking rock, and does not include downtime due to tripping or other operational activities. [8]

DTH drilling at Fraunhofer IEG has also proven that cuttings transport and required DTH hammer circulation flow rate are typically unbalanced, as the fast DTH ROP produces high volume of cuttings, requiring much more volume flow for their timely transport and proper hole cleaning, especially as only clean water is the choice of fluid. Thus, a sharp increase in ROP like in the case of a DTH hammer necessitates a likewise drastic or exponential increase in drilling fluid flow rate. In a reference case, 260 and 320 cubic meters of total circulation water volume removed 4.3 and 5.3 cubic meters of cuttings from a 6 ½ and 7 ¼ inch borehole, respectively. This was during the drilling of two 200 m deep boreholes for the utilization of shallow geothermal energy at the institute in Bochum. These number compare to similar percussion drilling endeavors elsewhere. [8]

This can be seen when looking at fluid circulation time versus drilling time or ROP; it is evident from IEG drilling data that over half of the overall time required to drill to TD is allotted to hole cleaning and fluid circulation for cuttings removal, meaning added or non-productive time (NPT). This is increasingly true for greater depths beyond 80 meters due to only clean water being used as drilling fluid, requiring relatively high fluid and cuttings transport velocities over 1 m/s, which are conventionally not encountered in deep, mud rotary type drilling. [8]

WP1 Task 1.3

Description

demonstrate that clean / ambient reservoir water can facilitate sufficient cutting transport and appropriate hole cleaning while minimizing logistical requirements and cost. One major purpose of drilling fluid is the transport of cuttings from bottom hole to surface. Common drilling fluids embrace properties such as thixotropy and adequate viscosity through additives. Today's downhole percussion drilling tools still are rather sensitive to impurities and abrasive materials in the drilling fluid. Therefore, it is necessary to facilitate cuttings removal and appropriate hole cleaning with nearly clear / ambient water, which has not been intensively enriched or altered with additives.	IEG GES Züblin

Overview

Drilling fluids do play a central and integral part in safely and economically creating a borehole. It is the fluid circulation system facilitating hole cleaning, wellbore integrity and well control during drilling operations. Moreover, it may well be utilized to convey some of its fluid hydraulic power to add mechanical power to the bit, in addition to pipe rotation and WOB. Good hole cleaning means timely removal and flushing of cuttings from the vicinity of the bit, plus subsequent transport of cuttings upwards from downhole to surface via the annulus within ROP speed during the well drilling process. Inadequate cuttings removal will eventually impede drilling. For deep drilling, cuttings removal from the wellbore is mostly affected by flow rate, drill string, bit geometry, hole angle, pipe rotation (ROP) and eccentricity. [5, 9, 10]

Especially in deviated or (long) horizontal boreholes, hole cleaning issues are persistent as cuttings accumulate along and around the pipe on the low side of the borehole: the pipe remains on the low-side and creates an uneven annulus, dividing it into high-flow and low-flow zones, thereby altering flow characteristics. Figure 1 shows a cross section of drill pipe, immobile cuttings bed, mobile cuttings and drilling fluid in an inclined borehole. [10]

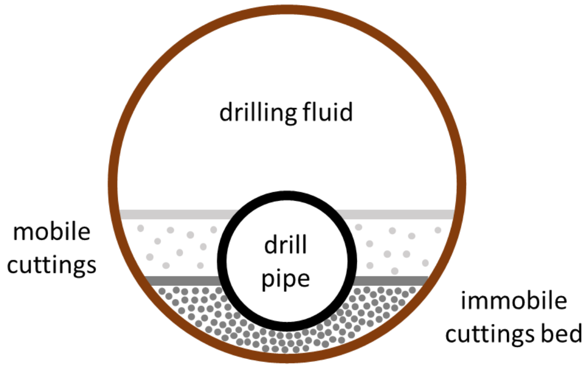

Figure 1: Drill pipe, cuttings and drilling fluid in deviated wellbores [10] - changed

Pipe rotation is common practice to overcome these hole cleaning issues. Rotation prohibits cuttings accumulations from building up and generally homogenizes the flow. However, it is when a pipe connection is made to allow for the further extension of the borehole, that pumps are stopped and the drilling fluid circulation system comes to a halt, impairing both cuttings transport and hole cleaning. Conventional drilling fluid restricts cuttings from falling back to the bottom hole through fluid-thickening and viscosity-increasing, so called thixotropic additives. However, it is currently not possible to utilize this type of thixotropic drilling fluid, employed in conventional drilling, in combination with DTH percussion drilling technologies: various mechanical components inducing the percussion mechanism are prone to failure when driven through a medium other than clear water. It is therefore necessary to facilitate cuttings transport and hole cleaning through clear water with no additives when utilizing percussion drilling technology. This makes flow velocity and adequate circulation of the borehole even more important. Standard mud rotary drilling practice suggests an annulus velocity of 0.3 to 0.8 m/s for good hole cleaning. [5, 9–12]

Method

For the assessment of cuttings transport, particle slip velocity was determined considering for buoyancy, drag resistance and gravitation. Figure 2 shows this model relationship for a particle submerged in a fluid in a borehole: all forces are related to the parameters of fluid and particle and the drag resistance is additionally dependent on the drag coefficient of the particle. [8]

For the Bedretto ST2 drilling operation, the fluid was just water and the resulting cuttings were fine-grained granite. Under ideal conditions, the slip velocity of the particle would be equal to the necessary cuttings transport velocity, though, for a realistic approximation, influences like particle size inhomogeneity, pipe rotation, wellbore wall roughness and others must be considered. This is achieved through the introduction of another factor accounting for all geological and drilling related issues, which further impair cuttings transport to surface. [8]

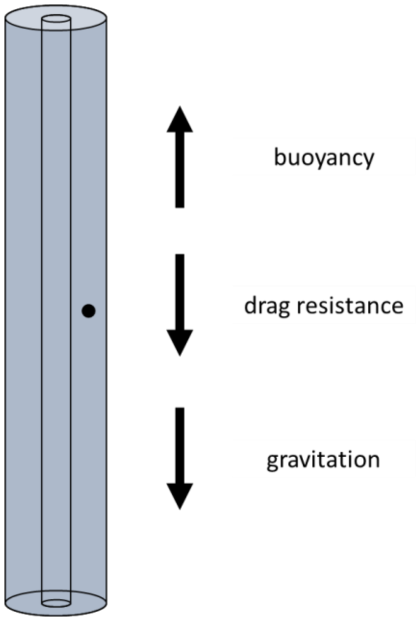

Figure 2: Model for slip velocity and cuttings transport [8]

Results

Drilling data of the ST2 borehole and collected cuttings were analyzed and evaluated in the laboratory yielding particle size range and mineral composition for volume and density values. Assessed cutting particles were fine and homogeneous in nature, corresponding to the high frequency working principle of the deployed DTH water hammer; i.e. lower frequency DTH air hammer would have yielded different cuttings particles. These particles facilitated cuttings transport and hole cleaning, with cuttings particles in the three-digit micron range, approximately 500+ µm and well below 1 mm, and their densities corresponding to the Bedretto granite. The drilling of the ST2 borehole in the BUL has proven the viability and feasibility of near horizontal percussion drilling with clear water as drilling fluid in a pilot up to 342 m MD or length. Though the initial inclination of the well was rather high at 54 degrees from vertical at well head, the remaining of the above mentioned, most important parameters affecting cuttings transport were optimized to facilitate adequate hole cleaning under these extreme deviated conditions. Flow rate was increased as needed, pipe rotation was upheld except when making-a-connection, and pipe eccentricity was ensured through centralizing elements along the BHA.

High circulation rate was maintained and cutting size is naturally small and rather homogenous with such DTH water hammers, facilitating adequate as well as timely hole cleaning with resulting ROP. Moreover, additional fluid circulation was possible and conducted during and after drilling halt and before new pipe connection. This was to transport cuttings in the slanted borehole to surface post drilling of each 3 m pipe joint. The contrary, an immediate halt of the pumps after drilling would have resulted in cuttings sinking to the bottom of the well, potentially clogging and plugging downhole tools and equipment. Furthermore, favorable, smooth wellbore wall conditions, evident especially through visual imaging of the video camera log shown in figure 3, due to formation (very hard rock) and the nature of the percussion drilling technology.

Figure 3: Smooth wellbore wall after DTH drilling (ST2) [13]

WP1 Task 1.4

Description

Perform a full-scale demonstration of the above technologies in the granite reservoir rock in the Bedretto Underground Laboratory BUL. Drill a highly deviated, near horizontal wellbore into granite rock at the Bedretto Underground Laboratory via industrial, hydraulic percussion DTH hammer in combination with ambient water as powering and drilling fluid. Well logging, MWD and discussion, report of all pertinent parameters (e.g. ROP) highlighting operation and implementation.	GES IEG

Overview

The Bedretto Underground Laboratory (BUL) is a field test facility of the ETH Zurich in the Bedretto municipality, Ticino, Switzerland. It is located in close proximity to the south entrance of the Gotthard Road Tunnel, off the city limits of Airolo. The BUL is essentially a gallery within the eponymous Bedretto Tunnel, an Adit to the Furka Rail Tunnel in the Saint-Gotthard Massif. The gallery is located approximately midway, 2000 m into the tunnel and is overlayered by 1100 m of Saint-Gotthard mountain range. This yields realistic confining pressures for tests conducted from within the reach of the BUL. As part of the activities and the demonstration in the BUL, a series of wellbores were drilled into the crystalline granite rock of the Saint-Gotthard Massif in the Alps. Fraunhofer and Geo Energie Suisse assigned the drilling of the ST2 borehole in the BUL to subcontractor Züblin AG as former partner H. Anger's Söhne, who were initially intended for the drilling work within the ZoDrEx consortium, opted to withdraw from the project in late 2019. All drilling and drilling related work were conducted by Züblin AG and consulted as well as directed by both Fraunhofer IEG and Geo Energie Suisse. During the actual drilling work, Geo Energie Suisse was continually present in the BUL overviewing the operation; Fraunhofer IEG was on site at times to consult with the proceedings, however, at the time, the COVID-19 situation started to become increasingly prevalent, rendering desired further presence and participation of Fraunhofer IEG in the actual drilling operation unfeasible.

Drilling Activity

In close cooperation, Züblin AG employed percussion hammer technology to drill through the hard granite rock of the Saint-Gotthard Massif. For this, a so-called DTH was utilized in conjunction with drill pipe and water as a drilling fluid. The drill pipes measured three meters a piece and the nature of the BUL did not allow for a vertical wellbore to be drilled into the granite. Thus, an initial angle of 54 degrees from the vertical was deemed necessary and likewise plausible for both proper operational undertaking and experimental setup, respectively. In this manner, a borehole measuring 8.5 inches (215.9 mm) in diameter was drilled to a measured depth (MD) of 342 meters. Subsequent to open hole testing, the wellbore was cased and cemented with 7-inch casing (159.41 mm).

As deviated or horizontal well sections represent an especially powerful mean to connect wellbore and reservoir and as due to the nature of reservoir rock being hard rock in hot dry rock (HDR) and enhanced geothermal systems (EGS), it is necessary to show that DTHs are capable of delivering deviated and directional wellbores with high quality. This inclined drilling operation with no deviation control whatsoever allowed for assumptions to be drawn regarding trajectory behavior and well path compliance of DTH technology in very hard rock. For a measured depth (MD) of 342 meters, an inclination drop of 13.7 degrees was determined for the bottom hole of the wellbore. Furthermore, an initial orientation (azimuth) of 220 degrees at the wellhead was deviated marginally at total depth (TD) to 222.8 degrees, with a maximum azimuthal deviation to 214.8 degrees at 173.5 m MD. The horizontal displacement (HD) of the wellbore was calculated to be 254.82 m, true vertical depth (TVD) is approximately 226.64 m. Considering the HD and the initial inclination at wellhead, this deviation is acceptable for no deviation control and in fact good with regard to wellbore deviation in rotary drilling. In fact, it is very presumable and probable that rotary drilling under the exact same conditions would have resulted in higher deviation both in inclination and orientation. Nonetheless, wellbore deviation encountered in rotary drilling is in part a result of the tendency of the bit to move due to its rotation. Therefore, the interpretation of well trajectory data as well as suggestions in the literature allow the assessment that for percussion drilling technology smaller wellbore deviation may be anticipated. [14]

Results

Additional logging verified the general smoothness of the wellbore through various employed post-run devices including optical tele viewer (OPT), acoustic tele viewer (ATV), caliper log and video-image camera log; both well trajectory and wellbore wall were determined to be generally smooth especially visually through color video-recording of the entire borehole. Dogleg severity (DLS) is approximately 1.23 degrees per 30 m for the ST2 wellbore. Nevertheless, a few large washouts were determined around 195, 260, 280 and 320 m MD. They were attributed through the logs to faults in the formation and thus were not regarded as a result of poor or inadequate drilling. In the initial open hole (OH) state of the wellbore, however, these washouts had to be considered for workover operations like the Radial Jet Drilling (RJD) stimulation. Necessary Run in Hole (RIH) and pull out of hole (POOH) of drill pipe for the RJD operation was planned accordingly. One local washout is shown in figure 4 and a caliper log for the entire borehole, which was calculated from the ATV log, is provided in figure 5. The caliper log shows that the borehole becomes narrower with depth, also showcasing the washout sections.

Figure 4: Local washout within ST2 borehole [13]

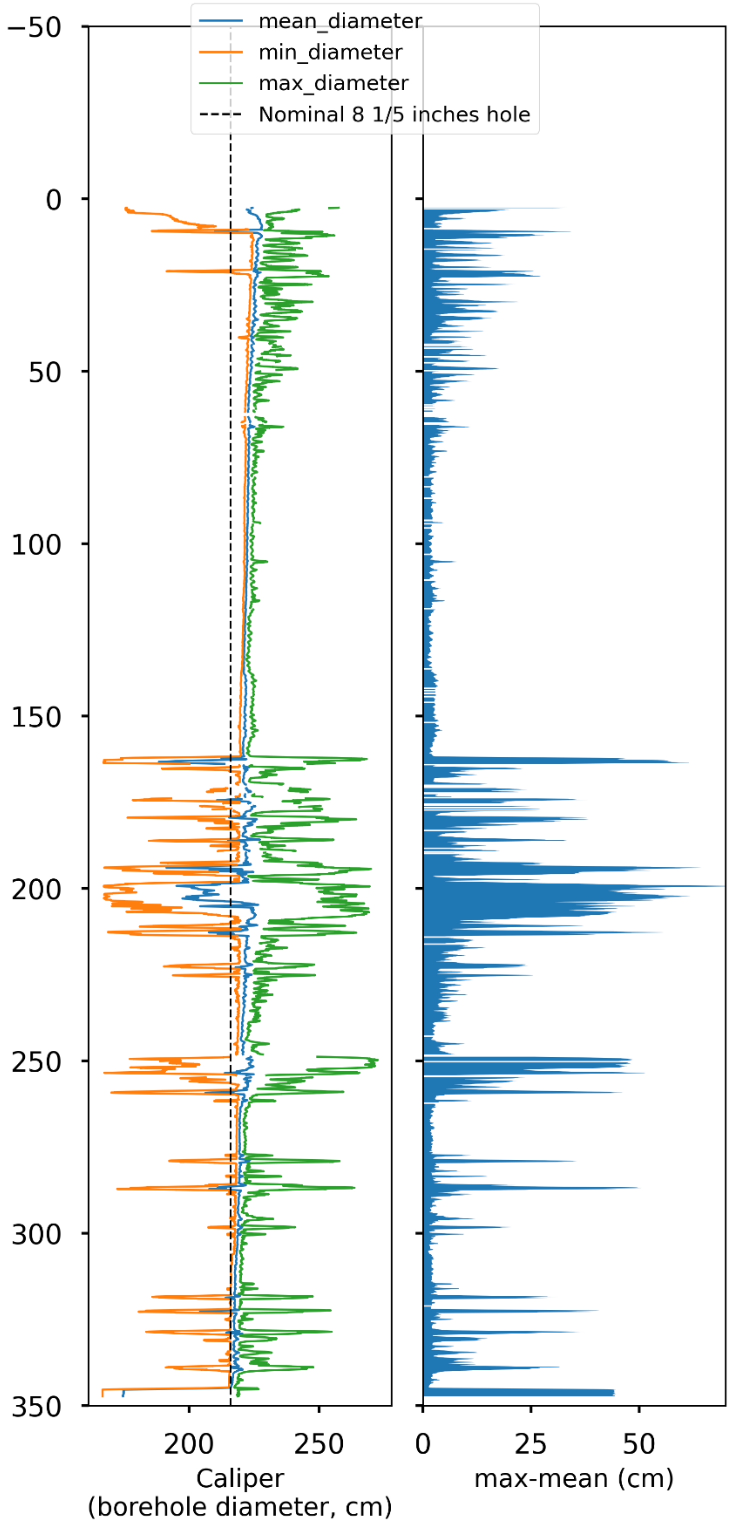

Figure 5: Caliper log of ST2 borehole showing sections with washouts [13]

WP2 Task 2.4

Description

Test and demonstrate the capabilities and limitations of short radius micro-drilling (HP jetting and DHT Hammer) to enhance connection to EGS reservoir in crystalline rock in the meso scale laboratory in Bochum and in the tunnel.	IEG GES

Overview

Productivity or injectivity of a well is attributed amongst others to reservoir permeability and near wellbore damage. Stimulation is performed to increase or restore formation permeability and to bypass damage in the vicinity of the wellbore. Stimulation is categorized into two main types of treatments, hydraulic fracturing above the formation fracturing pressure and matrix treatments below the reservoir rock fracturing pressure. The former treatment type targets the creation of new fractures, whereas the latter treatment type aims at restoring original permeability. Stimulation treatments are enhanced or tertiary recovery techniques, part of either well completion, workover or intervention operations. Furthermore, Radial Jet Drilling constitutes a stimulation treatment, which utilizes actual small-caliber drilling (jetting) for permeability enhancement, rendering it independent of but at the same time combinable with the aforementioned treatments. Figure 6 illustrates these treatments and their differences. [15, 16]

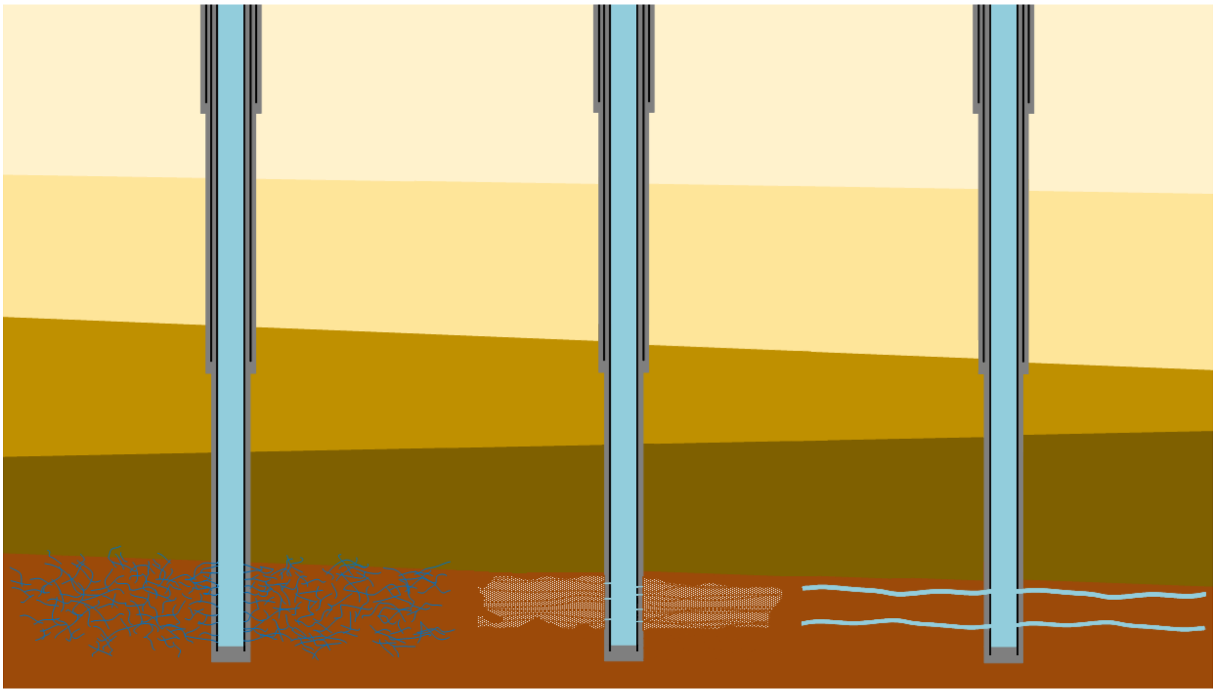

Figure 6: Possible reservoir stimulation techniques: hydraulic fracturing (left), chemical or matrix treatment (middle) and (mechanical) radial jet drilling and milling (right) [17]

Radial Jet Drilling

Radial Jet Drilling (RJD) is a stimulation treatment, which targets the boosting of wellbore-reservoir contact through the creation of small-caliber, radially-oriented lateral micro-drainholes along the production or injection zones of the borehole. It is essentially a treatment employing actual drilling for the purpose of reservoir stimulation. For this, RJD combines a series of technologies to enhance the communication between wellbore and reservoir, and to increase productivity or injectivity: directional drilling, short-radius wellbore deviation, whipstock-like deflection, sidetracking, coiled tubing technology, jointed pipe technology, hydraulic rock penetration and downhole bit drive techniques constitute what is referred to as RJD. Figure 7 outlines RJD as a technology combination. [16, 18]

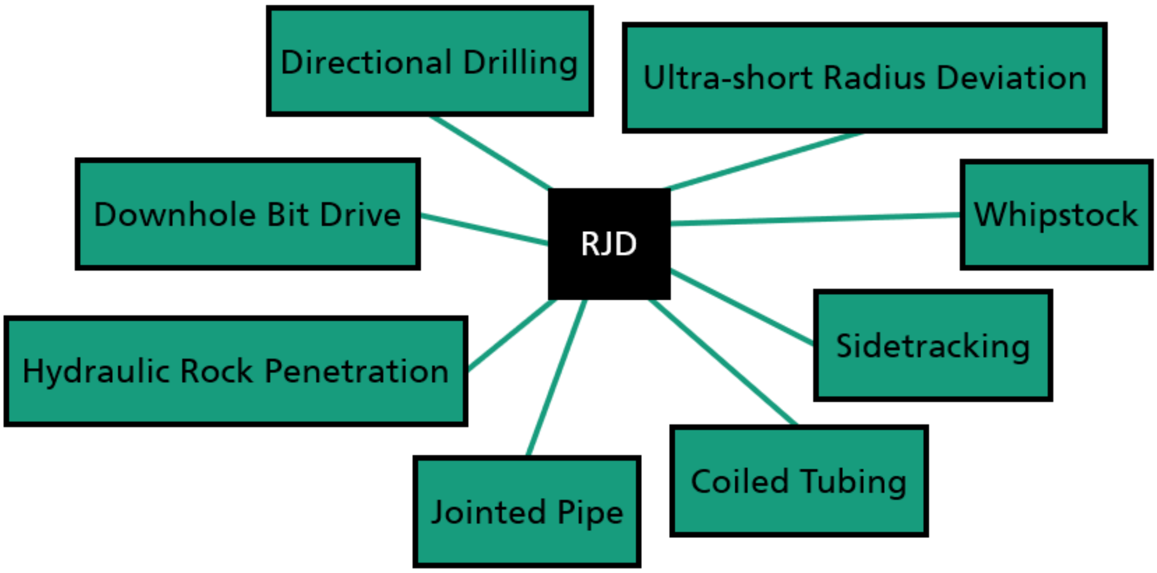

Figure 7: Various technologies at IEG combining radial jet drilling

Initially, the whipstock-like downhole tool or deflector shoe, which induces a deflection from the wellbore axis, is lowered into the wellbore via jointed pipe employing a small workover rig. Once the deflector shoe and other BHA components like stabilizers reach the target zone, coiled tubing is deployed to lower a hose with attached nozzle through the jointed pipe into the deflector shoe. During this process and thereafter, the jointed pipe maintains the deflector shoe in place. This allows for the deflection of the nozzle as it travels through the deflector shoe toward the wellbore wall or casing. At this interface, the nozzle initiates the sidetrack out of the wellbore to create the lateral. That said, the deflection toward the wellbore wall occurs solely within the gauge of the wellbore, rendering it an ultra-short deviation procedure with an inclination of up to 90 degrees. In cased boreholes, an ancillary casing milling operation precedes the sidetracking. Moreover, the nozzle is equipped with forward-oriented and backward-oriented orifices facilitating rock erosion and propulsion, respectively; the former drills (jetting) the lateral and the latter advances the nozzle along the lateral. Contrary to conventional drilling, the nozzle and trailing hose and coil are in tension downhole. Figure 8 is a schematic of RJD showing the most important components. [16, 18]

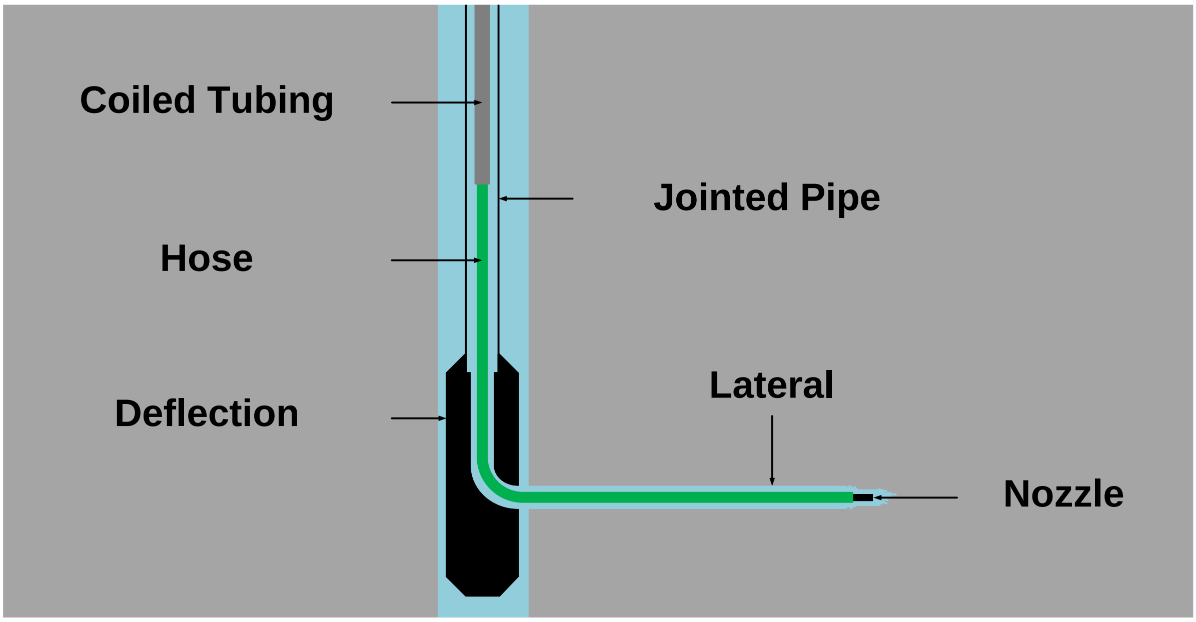

Figure 8: CT-based radial jet drilling: hose and nozzle comprising the jetting BHA, jointed pipe holding the deflector shoe

Upon completion of the micro-drainhole, nozzle and hose are POOH. By turning the drill string, it is possible to change the direction of the deflector shoe exit to subsequently drill additional micro-drainholes under other azimuth angles. In this case, the turning is usually performed as CT and nozzle are POOH and after inserting a gyroscope into the drill string via WL. The gyroscope is used to determine the new direction of the deviation shoe and transmits this to the surface through the WL. This information is what makes turning from surface for direction change and reorientation underground possible in the first place. The precise orientation of the deflector shoe ensures information about the azimuth of each micro-drainholes. [16, 18]

Jetting

Nozzles are used to control, direct and modify flow through alterations in cross-sectional area. Parameters like flow rate, direction, pressure etc. can be altered this way. Nozzles intended for drilling (jetting) utilize the hydraulic energy of the drilling fluid directly to break rock. Jetting with application in RJD is conducted with nozzles embodying forward-facing orifices and backward-facing orifices. At IEG, nozzles with different configurations were supplied through various manufacturers. Rotating and non-rotating nozzles are part of the portfolio of nozzles. Other differences in nozzle configurations include the ratio of forward-facing orifices to backward-facing orifices, the orifice number (forward and backward), orifice diameter, orifice shape, orifice exit angle as well as the nozzle material. Moreover, nozzle configurations also included modular or non-modular design: some nozzles were modular and orifice number, diameter etc. could be altered. Lastly, for rotating nozzles, bearing types were different for various types. Figure 9 shows a selection of rotating nozzles with two distinguishable parts, the rotating head and the main body.

Figure 9: Two rotating nozzles used during testing

At IEG, the target is the optimization of nozzles regarding application in hard rock found in EGS and HDR environments. The main problem with the adaptation of RJD to the geothermal industry lies in the rock disintegration process. The hydraulic energy of the circulation fluid utilized for the erosion (jetting) of the radial laterals into the formation is insufficient to do likewise in hard rocks. Thus, the nozzles target optimization with respect to already known parameters affecting the jetting process like head rotation, head standoff distance, fluid exit velocity, as well as phenomenon like fluid pulsation. Apart from this, improvement and enhancement of jetting to penetrate hard rock is only practical through increasing the total fluid pressure of the system: a costly approach, which scales up the technology defeating the initial purpose of cost-sensitive RJD as a competitor to other stimulation treatments.

Jetting Tests

Jetting tests were conducted at IEG under surface conditions as well as under simulated reservoir conditions. The former tests were carried out employing a yard test bench on the grounds of the drilling site of Fraunhofer IEG in Bochum, which allowed for realistic jetting tests regarding the governing operational parameters like the nozzle advance. The latter experiments were undertaken in a confined environment, the autoclave system iBOGS-mini in the laboratory building of Fraunhofer IEG; this allowed for more modifications and variation regarding the governing parameters of the actual jetting process. Moreover, full-scale RJD field trials were part of the demonstration in the BUL in Switzerland in the fall of 2020: this allowed for the realistic assessment of the previous efforts and findings toward the advancement of the RJD technology.

High-Pressure Yard Jet Testing at IEG Drill Site

One way to enhance the specific energy of a jet impinging on a hard rock surface is to increase its impact velocity through higher differential pressures across nozzle orifices outlets. Experiments with water pressures in the range of 500 to 1000 bars were conducted with a newly built yard test bench utilizing granite samples under atmospheric pressure. Various nozzle types were utilized for this series of tests as it was not possible to vary the general conditions like the surrounding pressure etc. Figure 10 shows this yard test bench on the grounds of the IEG drilling site. Figure 11 is a picture of the jetted sample Grimselgranite, while figures 12 and 13 show a close-up of a jetted excavation point or notch and its measured geometric shape, respectively. Visible through the inhomogeneity of the notch and the ledges along its depth, the respective excavation point was jetted through a rotating nozzle.

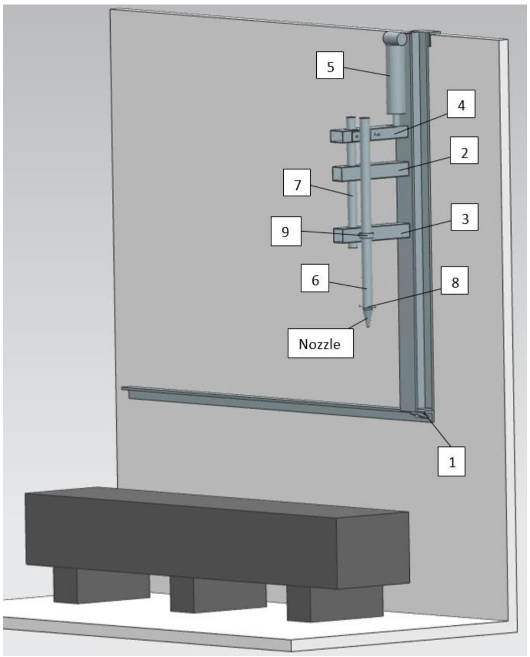

Figure 10: RJD Yard test bench setup

Figure 11: Grimselgranite block

Figure 12: Jetted notch

Figure 13: Shape of notch

The results show that it is very possible to drill (jet) the given granite sample utilizing only clear water if pressures in excess of 700 bars are achieved, indicating that much higher pressure regimes (factor two or even more) would lead to even greater success. However, it is obvious, too, through calculations and observations, that higher pressure regimes render the technology technically more demanding and ultimately much less economical; i.e. sturdier but heavier CT, hoses etc. with smaller diameters and associated higher pressure losses would be necessary. Furthermore, more sturdy high-pressure hoses would be demanding with regard to the bending forces along the defector shoe, possible decreasing or limiting the achievable deviation angle. Thus, sole pressure increases to achieve rock erosion may not be a sufficient measure for the improvement of jetting as part of the holistic RJD technology.

Laboratory Jetting Tests at IEG

The literature suggests that dynamic effects like the initial stagnation pressure peak (water hammer pressure effect) and pulsation have an influence on the rock erosion process in general. Thus, experiments with continuous and pulsating waterjets were conducted under simulated reservoir conditions in the autoclave iBOGS-mini, shown in figure 14, to compare jetting performance and outline a possible trend. [19]

Figure 14: Autoclave i.BOGS-mini with linear feed system, with rock sample simulation depth down to 2,000 m

The experiments were undertaken simulating hydraulic conditions down to 2.000 m depth. Pulsation was induced through sole mechanical interruption of a continuous waterjet. The mechanical interruption via shutter mechanism allowed for pulse intervals as short as 50 ms. The impact factor standoff distance between nozzle and rock sample was at max. five times the nozzle diameter, while the tested rock type was Obernkirchener sandstone. Exposure time was between 50 and 5.000 ms for continuous jetting and up to a 100 single pulses of 50 ms duration for pulsating waterjets, rendering that total exposure time and water volume applied to the rock constant at 5.000 ms. Created notches are shown in figures 15 to 17. The 50 ms of continuous jetting shown in figure 16 had little effect on the rock surface, with the other two figures 15 and 17 showing clearly visible notches after a respective total exposure time of 5000 ms. However, the impact of the pulsed jet on the surface in figure 17 is much more severe and therefore more effective. This is because one of the main erosive effects for both continuous and pulsating waterjets is the initially occurring water hammer pressure effect, which is approximately ten times more impactful than the average stagnation pressure. It occurs at the very first contact between waterjet and rock surface and renders short and pulsating water jets especially prospective as they repeat this impactful effect.

Figure 15: Oberkirchener sandstone 5000 ms

Figure 16: Oberkirchener sandstone 50 ms

*Figure 17: Oberkirchener sandstone 100*50 ms*

Subsequent to jetting, the filling of the excavated notches with fine-grained sand (150 µm grain size) allowed for the calculation of the exact volumes down to an accuracy of 4 mm³. The pertinent hydraulic power was calculated to be 20 kW with both the flow rate and differential pressure across the nozzle. Excess hydraulic power would boost jetting performance even for continuous waterjets, though, the trend shows that pulsating waterjets would perform better regardless. Figure 18 shows a completely jetted sample beyond the initial excavation or notching phase and figure 19 is a picture of a jetted sample in hard rock.

Figure 18: Jetted sandstone, rotating nozzle

Figure 19: Jetted and notched Grimselgranite

Bedretto Underground Laboratory Jetting Tests

A series of jetting tests were conducted in the then open hole ST2 borehole of the BUL in the fall of 2020 as part of a two-week field test and demonstration. The setup of the demonstration is elaborated upon in task 2.5, with the difference being the rock disintegration method only: hydraulic rock erosion versus mechanical rock drilling. The jetting tests were conducted employing several modular non-rotating nozzles with different orifice diameters. These nozzles were connected via a flex hose to the CT, which facilitated RIH to the deflector shoe exit. The modular assembly of the nozzles allowed for additional backward-oriented orifices and more tension along the hose and the CT upon need. Non-rotating nozzles were particularly selected to avoid nozzle stall encountered in preceded yard and laboratory testing. Figure 20 illustrates the downhole setting during the jetting operation. Part of the hose and the nozzle are in the deflector shoe, with the latter initiating the micro-sidetrack. The CT may not be deviated through the deflector shoe. Two sets of adapters and stabilizers complement the BHA, respectively.

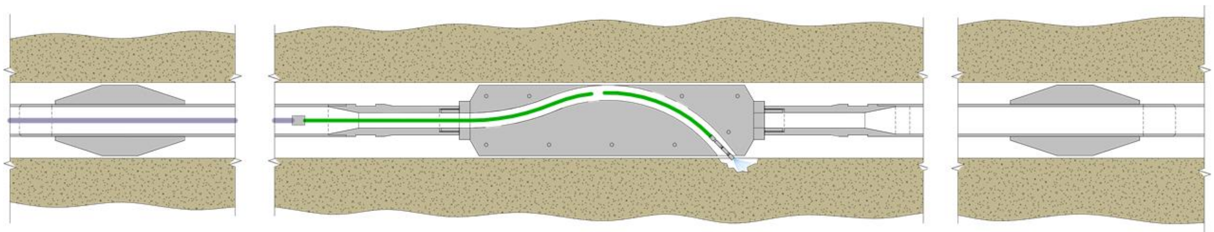

Figure 20: ST2 jetting BHA with coil deflector shoe, stabilizers, adapters; hose and nozzle

The operation lead to the creation of small notches in the granite, visible also on logging data provided after completion. Moreover, an attempt was made to erode a rim into the granite formation through continual rotation of the deflector shoe with the rotary table, thereby changing the orientation of the exit along the total 360 degrees. Figure 21 shows a notch in the Bedretto Granite and figure 22 is an image of the groove eroded into the granite formation. Figure 23 shows the deployed modular nozzle with several thrust-modules facilitating enhanced advancing push through more backward-oriented orifices.

Figure 21: Jetted notch in ST2 borehole [13]

Figure 22: Jetted groove in ST2 borehole [13]

Figure 23: Complete (rotating) modular nozzle assembly deployed during BUL experiments

Discussion

Experiments conducted under atmospheric and reservoir type conditions yielded various results for the nozzles and the overall jetting process. During the experiments, it was observed that global cracking occurred in the specimen due to high static pressures, eventually halting the jetting process. A core holder was designed to preload the samples to alleviate or even prevent global cracking from occurring. Another challenge of the jetting process was found to be the sensitive control of weight on bit (WOB) and the continuous advance of the nozzle. Direct contact between rock surface and rotating nozzles caused major stall as no substantial torque is generated through the spinning. Nevertheless, a particular, rather small window of standoff distance between nozzles and rock surface must be maintained throughout the jetting process to achieve best jetting practice and avoid the forming of large washouts or doglegs. An optimized setup incorporating high precision linear nozzle advance facilitated exactly this in more advanced experiments. Measurements verified that pressure, flow and acoustic emission correlate with nozzle rotation or stall. This made the employment of rotating nozzles in the BUL undesirable as the field trial was deemed much more prone to error or failure than the tests conducted in the yard and in the laboratory. Several new approaches to prevent the rotating nozzle from stalling were considered but no design proved viable. This why notching was conducted in the BUL for the jetting process. Figure 24 illustrates the problem with the continuous advance of the nozzle and figure 25 showcases the relationship between nozzle stalling and parameters like flow rate and pressure. It is believed that experience with the jetting process for particular setting (nozzle, rock, equipment etc.) allows for the correct assessment of nozzle advance, i.e., finding the sweet spot of correct nozzle advance for a given setting (pressure, flow rate, rock type, equipment) is difficult and a matter of data for different jetting settings.

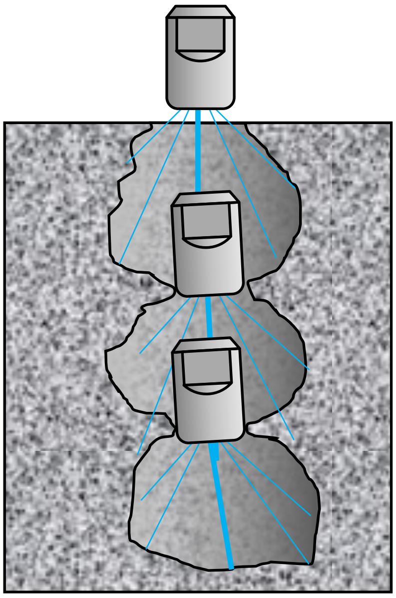

Figure 24: Nozzle bit stalling due to washout

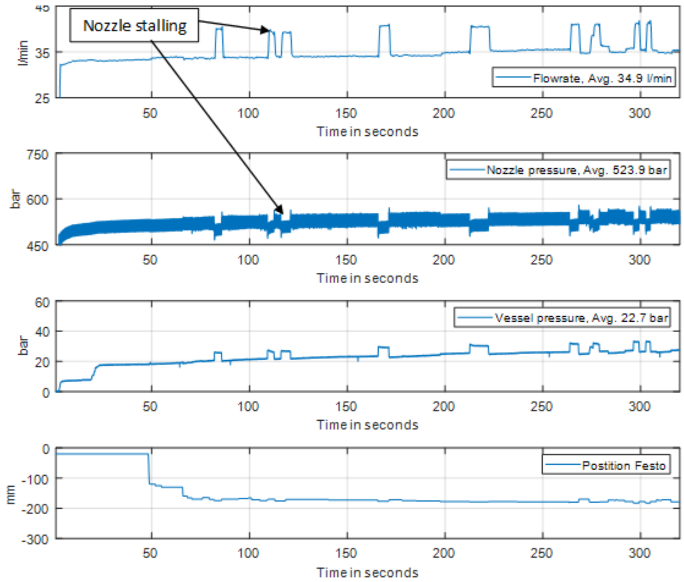

Figure 25: Correlation between stalling, flow rate and pump pressure

Compact Rotary Percussion Drilling Unit

Innovative, compact percussion drilling systems are under development and investigation at IEG. Within ZoDrEx, a rather compact downhole percussion-based bit drive had been evaluated for application within slim radial jet drilling operation relying on ultra-short or sharp, up to 90 ° turns to enter the formation. The new tool is a rather compact percussion unit with integrated rotation capabilities und thus, powering and rotating its drill head at the same time. It originates from workover within the subsurface sewer industry, removing harder, mineral type dirt. Recent applications within the mining industry expand possible utilization of such tool. Fraunhofer IEG is further developing it now to possibly use it for reservoir enhancement operations within the (deep) geothermal industry and thus, bridging the gap to the drilling industry. Just like in any downhole BHA within deep drilling operations, the circulating fluid powers the tool and thus, generates both rotation and percussion within this compact setup. However, when one part fails to move or stalls out, it also terminates the other movement. The bit section may be varied according to rock type, whereas the main body just has various outer diameters due to hole size and power requirements. However, smallest diameter currently is 3,5 inches with a length of up to a foot, making it very compact for the deep drilling industry, but still rather large for micro type RJD operations being looked at within this project. The assembled tool body comprises three elements necessary for the generation of rotation percussion and milling: valve control unit, percussion mechanism and rotation mechanism. The former sits atop the main body, the subsequent percussion mechanism is in the middle of the main body, and the rotation mechanism is at the end, transmitting a rather continuous rotation movement to the percussion action. Figure 26 outlines the two visually distinguishable parts of the compact rotary percussion milling drill head. [20]

Figure 26: Example compact rotary percussion drilling unit

Experimental Setup

CRPD tests were part of a thesis at Fraunhofer IEG and the experiments were exclusively conducted as yard tests on the drilling site of Fraunhofer IEG. A new yard tests bench was designed and built for the CRPD tests. The experimental setup is as follows: The CRPD is attached to either a flexible hose or a pipe, which are in turn mounted to an elevator allowing for axial movement. The elevator runs on a chain drive powered by a hydraulic motor. The hydraulic motor is connected to a hydraulic unit with tank and pressure reducing valve. The reducing valve is crucial for the control of WOB for tests conducted with pipe; tests with the hose do not allow for additional WOB. The specimen is clamped and fastened to the underframe of the test bench. A guiding pipe is mounted to the specimen to facilitate a proper interface between CRPD bit and rock; this is to reproduce downhole conditions like those encountered when deviating or deflecting the wellbore. A high-pressure pump continuously feeds the CRPD with pressurized clear water from a water hydrant. A camera is deployed for monitoring purposes as the tests are conducted in a contained area prohibiting a visual on the experiments. Figure 27 is an illustration of this test bench. [20]

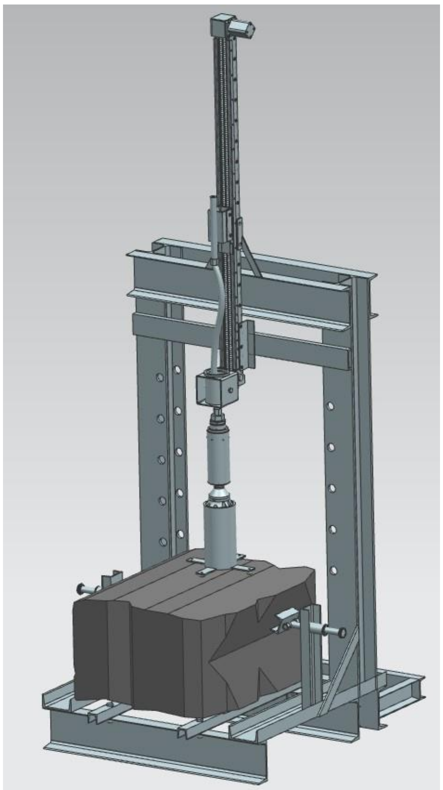

Figure 27: Rotary percussion testing device [20]

Compact Rotary Percussion Milling and Drilling Tests

The following is an overview of the execution of the yard tests: the CRPD is lowered into position to the surface of the Odenwaldgranite specimen and WOB is applied and adjusted through the pressure reducing valve. Thereafter, the video monitoring is commenced as the high-pressure pump is started and the CRPD initiates the drilling. Only then are test parameters of pressure and flow rate recorded and timekeeping is started. Once the test duration is reached, all abovementioned are stopped, ceasing the test. The CRPD is removed from the rock surface and the depth of the drilled section is measured. Finally, CRPD, bit and ancillary equipment are inspected for wear and abnormalities. Tests were conducted with a series of bits, one of which was the original bit of the CRPD. Alterations and modifications of the original bit were conducted to enhance the performance of the CRPD in granite. Bits of known suppliers of percussion drilling technology were adapted and utilized during the tests, too. Figure 28 shows various bits utilized during the tests. [20]

Figure 28: Bit development example for compact rotary percussion unit at IEG [20]

Results and Discussion

Numerous tests were conducted using a compact rotary percussion unit, CRPD. Drilling tests lasted up to half an hour in Odenwaldgranite and both setups were used, (flexible) coiled tubing as well as regular jointed drill pipe. WOB was varied greatly to help find the optimum drilling operation parameters. Thus, WOB was varied from a few hundred newtons to several kilo newtons. Flow rates changed as well, leading to differential pressures variations by factor four, reaching a maximum in the range of hundred bars. In general, such CRPD drilling within the Odenwaldgranite rock was successfully, though ROP values were rather moderate and comparable to those of standard PDC or tri-cone type rotary drilling in such hard rock. This may be partly due to the only few hours of testing: more extended testing mostly may result in more favorable ROP and drilling data. However, for the scope and intention during the ZoDrEx project this kind of tool was chosen to be not utilized more due to its geometric size and thus, downhole handling and sidetracking within the given, narrow expectations of the project partners and the overall goal. Figure 29 shows drilling with the CRPD. [20]

Figure 29: Bit testing results with compact rotary percussion in Odenwaldgranite [20]

Deflection

Whipstock

A tool placed into the wellbore at the KOP initiating deviation or further deviation along the trajectory. Its function is basically a kickoff foundation as it is composed of material harder than surrounding material like rock, casing or cement and as it is shaped like a wedge offsetting the bit face toward the wellbore wall or the casing, i.e. the whipstock forms an impenetrable obstruction along the wellbore, which thereof alters and offsets the bit face to initiate a new deviated wellbore section. The whipstock is the first deviation Tool with widespread application in drilling, it may be employed at the bottom hole or anchored at some intermediate depth in open and cased hole. [5]

Sidetracking

Drilling of a secondary wellbore away from a primary or main wellbore. The newly drilled secondary wellbore is referred to as the sidetrack. In conventional drilling applications, sidetracking may be necessary due to a fish, collapsed hole section or multilateral well design. Sidetracking is an integral part of Radial Jet Drilling. Regrading RJD, it describes the drilling of laterals or radials for the connecting of wellbore with reservoir; i.e. every lateral or radial is essentially a single sidetrack connecting borehole and formation. [9]

Deflector Shoe

A theoretical approach for the calculation of the deflection path within the deflector shoe was outlined. A two-dimensional approach takes into consideration width and length of the RJD tool, which are represented through a rectangle, as well as the deflection pathway (guiding bore through the deflector shoe), which is represented through a quarter annulus. This results in the bounding of the rectangle by the quarter annulus and the long sides of the rectangle to be tangent and secant to the respective quarter annulus inside and outside curve. An additional clearance between rectangle and quarter annulus to facilitate tool guiding concludes the model of the approach, allowing for geometric relationships between these parameters to be drawn. This eventually leads to an approximation of the possible inclination angle for the respective RJD tool. The approach is presented in figure 30. [17]

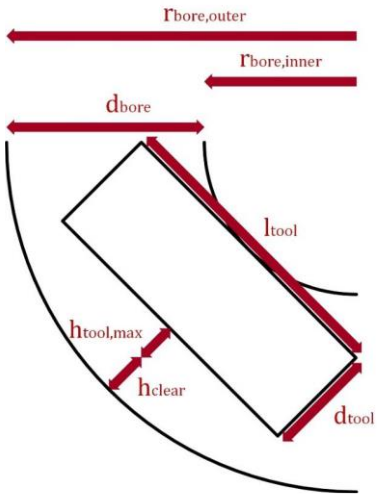

Figure 30: Side view of possible downhole deflection path [17]

A range of deflection and deviation tool prototypes for different IEG RJD technologies have been designed, built and tested. The abovementioned theoretical approach as well as experimental data was used for the design of a deflector shoe. Main constraints were found to be the dimensions of nozzles and other RJD tools (turbine, CRPD). These dimensions resulted in different possible deviation angles, with the CRPD consequently deemed unfit as a RJD drilling tool. The working principle of the tools constituted another important constraint in the deflector shoe design process. For original RJD, employing nozzle and clear water, wear and tear is much less of an issue than for tools deploying mechanical drilling. Mechanical drilling action renders the deflector shoe much more prone to abrasion; the turbine is characterized by very high rpms and the CRPD adds a low rpm percussive movement, which the deflector shoe must be able to sustain. Moreover, the angle the respective RJD tool achieves is believed to have an effect on the initial drilling success or commencement of the sidetrack. An orthogonal or 90-degree angle is favorable in many regards to alleviate the initiation of a window in formation or casing as e.g. an inclination of less than 90 degrees increases the distance which must be drilled through the casing; evokes operational difficulties (jamming) due to the gap between the deflector shoe and the formation or casing wall; and leads to potentially misaligned guiding (an offset inclination) out of the deflector shoe. Nevertheless, an inclination angle of 90 degrees is possible for nozzles only regarding usual casing or open hole diameters in the production section of the wellbore. Figure 31 showcases the deflector shoe deployed in the BUL field demonstration.

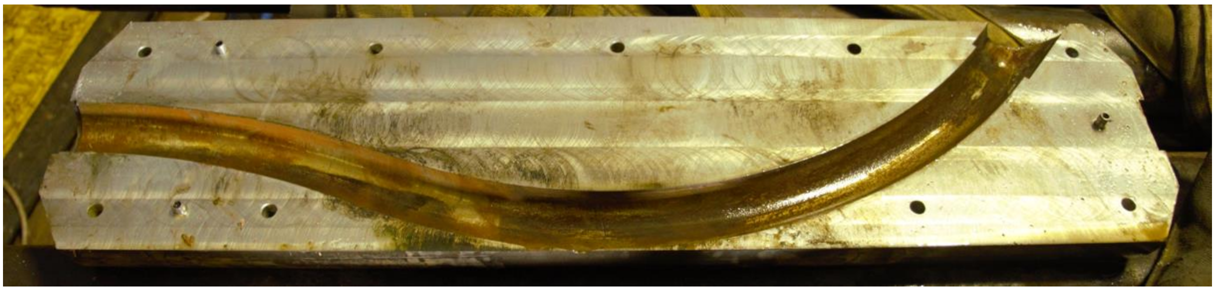

Figure 31: IEG´s Deflector shoe as utilized within the ZoDrEx field tests

WP2 Task 2.5

Description

Demonstration of the ability to connect granite formation from a cemented liner through jetted holes (notches). If safe and available at a reasonable cost, a test of perforation charges could also be attempted.	IEG GES

Overview

Downhole Bit Drives

Utilizing the energy of the drilling fluid circulation system for drilling is possible through the deployment of downhole bit drives. Part of the BHA, these drives convert hydraulic energy into mechanical energy, which ultimately supplies the bit, i.e. the rotation of the bit is induced through the bit drive and not string rotation. Moreover, a downhole bit drive may also be as simple as a nozzle if the hydraulic energy of the drilling fluid is utilized for the drilling action directly. In conventional drilling technology, two types of bit drives are prevalent: the positive displacement motor (PDM) and the turbine, whereby the usage of the former overshadows that of the latter. They are deployed in combination with directional assemblies like bent subs and bent housings to achieve wellbore deviation. [6]

Various downhole bit drives were evaluated at IEG for application in RJD, so-called micro drilling tools. This idea of incorporating a new element into the present framework of RJD through the introduction of actual mechanical drilling is part of the novel approach at IEG. Amongst these micro drilling technologies are the compact rotary percussion milling drill and the turbine, the latter of which is elaborated upon in the following.

Micro Turbine Jet Milling Tool

A mechanically supported, downhole jet bit drive is being developed at IEG and gradually finding its application within RJD operations. It is a successive invention out of the high-pressure rotating nozzles having been widely used within RJD so far. It finally became even a separate project called micro turbine drilling (MTD) to further develop this technology. Fundamentally, the so-called micro turbine converts the stored, hydraulic energy within the water into rotation necessary to turn a special bit. Subsequently, this makes for mechanical milling as the bit is in contact with the rock surface that needs to be cut or milled away, requiring also some force or WOB. The micro turbine is rather compact and comprised of all standard pieces like bit, stator and rotor with impeller and drive shaft. The main body and function of such a turbine is to convert the fluid´s hydraulic energy into rotation and thus, mechanical energy. The drive shaft then transmits this rotation to the bit, allowing for normal, mechanical drilling and milling of the minerals or rocks. The required WOB necessary for the milling or drilling is simply induced hydraulically through backward oriented thruster nozzles, the commonly known technique within any RJD system, rendering it also a self-propelled operation. [21]

Bedretto Underground Laboratory Field Testing

The 8.5-inch ST2 borehole in the BUL was cased with a 7-inch casing in the summer of 2021. This allowed for the application of the adapted RJD system with the micro turbine, facilitating the penetration of casing, cement and rock in a single run; original RJD utilizing hydraulic energy for the rock erosion is unable to penetrate materials like metal and an ancillary milling operation with a small-diameter PDM and a flex shaft miller is necessary adding another trip to the operation.

Operation

Main components of the field trials in the gallery of the BUL included one high pressure electric pump, two sets of pipe stacks, one rotary table, one coiled tubing unit, one compact hoisting unit and several waste and water tanks. These main bulky components and their arrangement are illustrated in figure 32 in a visualization of the gallery. All equipment was transported into the BUL gallery deploying a narrow-gauge electric vehicle and trailer.

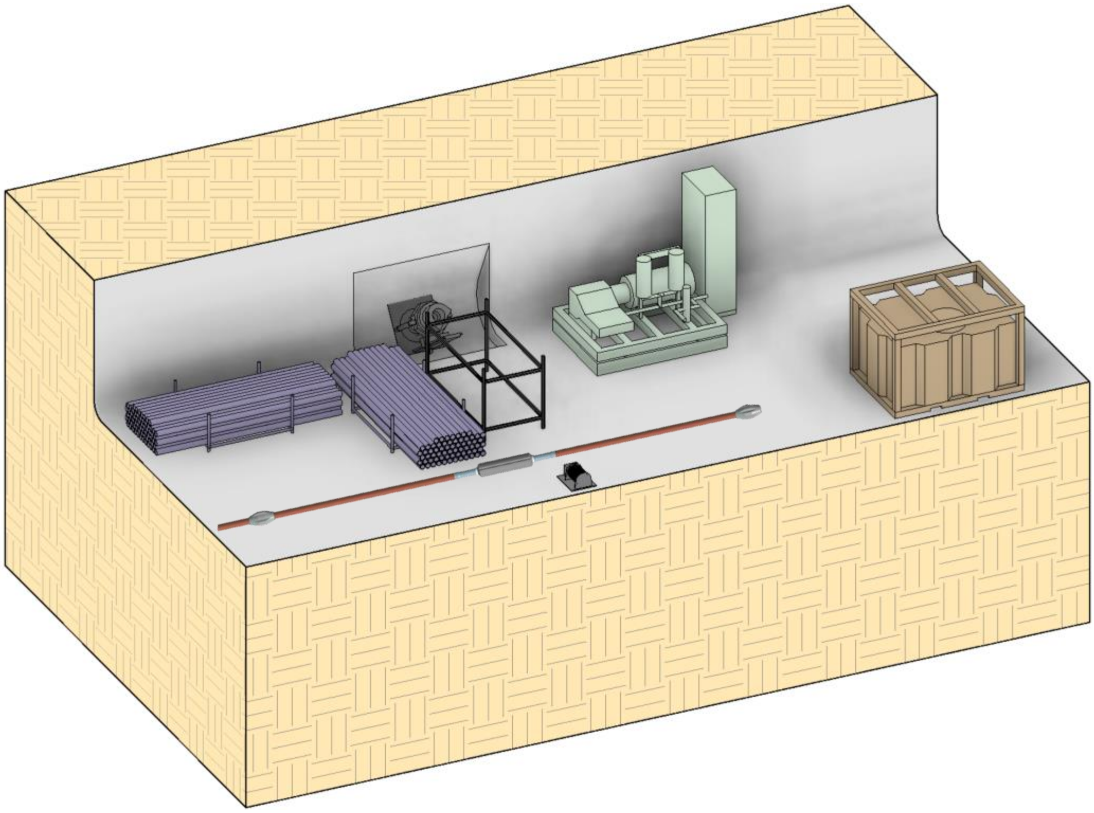

Figure 32: Site setup in BUL of IEG´s RJD equipment before RIH; pipe stacks (purple), triplex pump (green), rotary table (atop well head), water tank (yellow), BHA with deflector shoe and auxiliary tools (in front of pipe stacks), hoisting unit (in front)

Preparatory work in the gallery included usual rig-up tasks and safety measures. The rotary table was attached to the well head; pipes were greased and checked for collapses; the hoisting unit was checked; pump and flow lines were set up etc. The rotary table features gripping pads capable of holding onto drill pipe for rotation and small axial movement. This facilitates the correct azimuth and depth adjustment during radial drilling. The BHA included top stabilizer, top adapter, deflector shoe, bottom adapter and bottom stabilizer. The BHA was RIH on the pipes. The hoisting system allowed for RIH and POOH of pipe. Slips suspended the pipes whenever making or breaking connection and during the micro turbine operation.

Micro Turbine Milling Tests

The micro turbine milling operation was commenced when the desired depth had been reached. For that, the high-pressure pump was connected by flow lines with the coiled tubing unit at surface. The

CT, being connected to the turbine BHA downhole, was RIH through the pipe into the deflector shoe. Then, the mechanically supported sidetracking was initiated by milling a hole through the steel casing first. The same bit and jetting BHA then allow for continued jetting and milling into the surrounding rock, saving already one round trip out of the hole as is necessary otherwise within usual RJD operations, as normal casing milling is conducted differently and much slower. Upon conclusion of the radial lateral, the CT string with BHA was POOH. The downhole orientation of the deflector shoe was determined and verified post run utilizing a downhole camera; being lowered through the pipe to the top adapter, which had been marked and prepared prior for basic orientational directions. As the downhole camera was compact enough to also pass through the deflector shoe, it allowed for rather good assessment and evaluation of the micro sidetracks having been produced previously. Visualizations of any micro laterals, boreholes, or notches and pathway approximations thereof were possible in this way.

Figure 33 is schematic of the RJD process applied in the field tests at the BUL. A continuous supply of clear water from tank feeds the high-pressure pump, which pressurizes the water sending it downhole via the CT to the micro turbine. Downhole, micro-drainholes are created in the formation as rock is disintegrated into cuttings, which flow up the annulus to the waste tank in the BUL gallery.

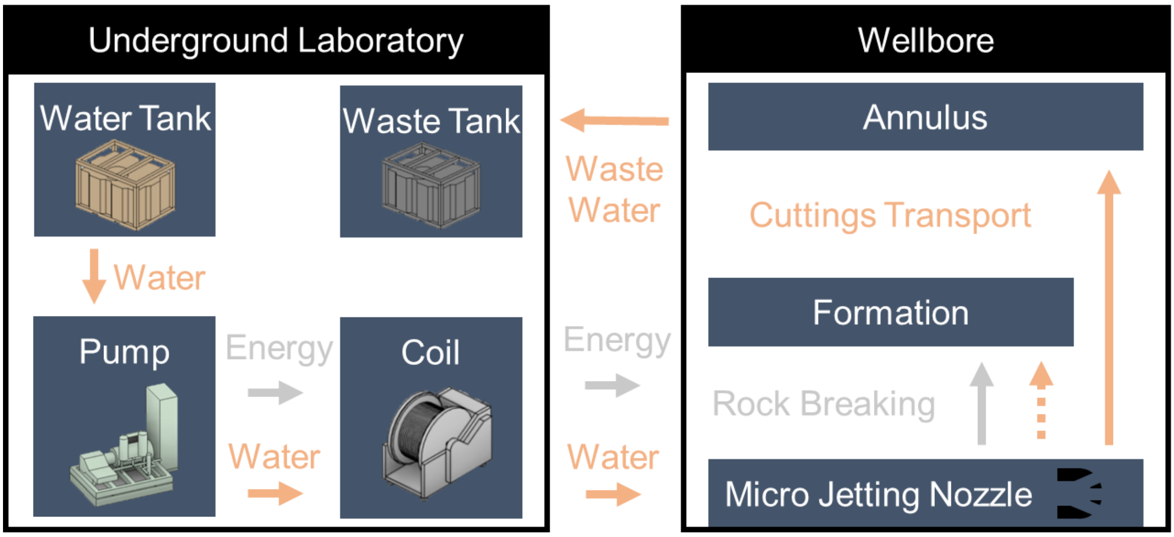

Figure 33: Equipment for IEG´s RJD testing in the BUL laboratory

For the creation of micro-boreholes under various azimuth angles at different depths, the drill string was extended or shortened after removal of the turbine from the wellbore; i.e. the drill pipes were added or removed after CT and turbine had been removed from the drill string. Without removal of CT from the drill string, it is not possible to lengthen or shorten the drill string, rendering the deflector shoe immobile. Figure 34 shows the deployed drill pipes.

Figure 34: Pipe used to set and orient deflector shoe and BHA

Results and Discussion

Several micro-boreholes and notches were created through the micro turbine in an attempt to establish communication between wellbore and reservoir through the cemented casing. High-angle and low-angle exits were made from the deflector shoe to create sidetracks with differing orientation angles (azimuth); this likewise resulted in the variation of the sidetrack inclination angles as the ST2 wellbore is deviated. The length of the sidetracks was purposefully limited to the vicinity of the wellbore in an attempt to focus on the near-wellbore damage. Figure 35 is an image of a sidetrack from the ST2 wellbore and figure 36 shows the log to the same micro-sidetrack; these figures show the results of micro-sidetracking conducted in the open hole state of the ST2 borehole. The data shows the success of the mechanical rock destruction process in hard rock like the Bedretto granite. However, there is room for improvement of operational capabilities as field trials were limited and a handful during the project. An issue which occasionally occurred and must be resolved is the tendency of the drilling tool (this is also true for the jetting tool) to jam downhole, rendering POOH very difficult at times. For the micro turbine this has led to complete deadlock with much effort going toward POOH. It is believed that the interface between deflector shoe and wellbore may have provided a state which allowed for such jamming of the turbine. This interface is essentially comprised of the deflector shoe exit, the wellbore wall and a gap between the both. Investigations into resolving the issue are ongoing and actually part of the MTD project. Another issue, which was observed during the BUL tests, was the creation of tortuous sidetracks with ledges. This is the result of the turbine to recentralize after the creation of an initial window, possibly because of whirling of bit and turbine or the effect of the hose on the drilling dynamics.

Figure 35: Milled sidetrack in ST2 borehole wall [13]

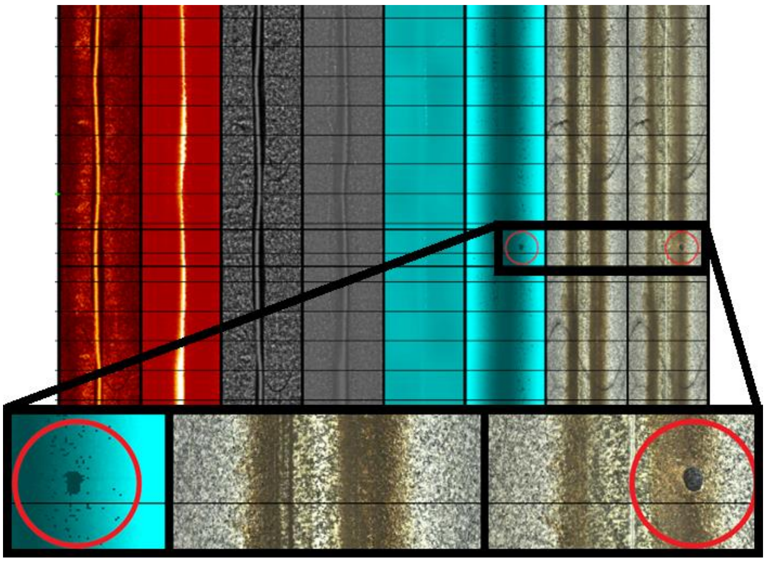

Figure 36: Log of sidetracks and notches [13]

Moreover, current RJD operations like in the BUL demonstration necessitate the allocation of a substantial amount of time to the azimuth-specific reorientation of the deflector shoe for respective micro-sidetracks, rendering non-productive time (NPT) a real issue as up to twenty percent of the operation time is lost in this way. Additional NPT arises from the necessary change of the depth position of the deflector shoe to treat the entirety of the reservoir thickness or target formation; only this ensures maximum possible contacting of the reservoir by the wellbore, preventing inflow performance issues from problems like partial penetration etc. The abovementioned NPT is a direct result of extra tripping of CT and ancillary equipment, i.e., at least two trips are required for the reorientation of the deflector shoe and one trip is required for the changing of the deflector shoe's depth position. This issue of tripping NPT must be addressed to foster RJD technology and make is more attractive.

Conclusion & Outlook

Numerous high-pressure jetting and RJD type technologies ranging from simple, standard static nozzles via compact percussion all across to mechanically supported milling and drilling technologies have been investigated, analyzed, carefully chosen and finally proven within IEG´s part of the ZoDrEx project.

Especially, their capabilities regarding basic destruction or erosion and ROPs in hard rock, here mainly granites, have been under development and evaluation. The most promising techniques, e.g. new (rotating) nozzle types and their control, and mechanically supported micro (turbine) milling were successfully utilized together with the ZoDrEx partners for workover and reservoir enhancement of certain, previously drilled boreholes in the Bedretto Lab. These large, near horizontal "production" type holes show cased state of the art DTH hammer drilling with very low trajectory drop for such extreme deviated drilling conditions, also yielding very smooth borehole walls with few washouts and doglegs overall. Cuttings were transported to surface successfully and timely during that percussion drilling process merely relying on clean water only, while the borehole was maintained free of fill and accumulated cuttings throughout drilling operations.

Furthermore, a compact percussion drilling unit was tested to scale down on conventionally long and bulky DTH technology to possibly facilitate very sharp whipstock-like deviation thereof. Nevertheless, mainly due to their geometric size and dimensions, IEG saw them currently being unfit for this RJD stimulation application within the framework of the ZoDrEx project. This drawback is a result of the currently required and prevailing physical size and dimensions of such a compact percussion drilling tool, as current RJD processes do necessitate much more compact downhole BHAs and milling and drilling tools for the ultra-short deflection radius of often near 90° within a 6-inch diameter.

As mentioned, various types of nozzles were tested and optimized for application in hard rock, mainly granites, under simulated reservoir conditions in IEG´s laboratory, testing on IEG´s drill site as well as under real downhole conditions in the BUL. Some of them have well proven to be viable for notching, erosion and excavation of notches and point spots in hard rock. However, more research is needed to facilitate even more reliable, faster und thus, more economic jetting of the near wellbore area for improved communication and finally, enhanced production between wellbore and reservoir. Application of traditional jetting (e.g. RJD within O&G) is limited to softer rock types, or else demanding upscaled technologies as have been developed now within ZoDrEx. Better nozzles including rotation and pulsation, control and understanding of the process, and finally mechanically supported micro (turbine) milling has changed and widened possible applications drastically and will continue to do so. E.g., the latter mechanical micro milling has made required steel casing milling much faster and more reliable, even saving one run or round trip as the same tool can be used to mill the rock as well as to create the lateral. Thus, several micro holes and notches were successfully created out of the casing in one run without tripping and bit changes into hard the granite rock of the Bedretto formation.

Furthermore, current RJD systems may be hampered and slow for further success and application in the industry, as currently very slowing tripping is always needed for updated axial / azimuth orientation and to change the horizon. That is why Fraunhofer IEG is looking into further research of general micro drilling technologies including operational setup and (downhole) controls. Currently at Fraunhofer IEG, new project ideas and proposals are underway through projects like Micro Turbine Drilling (MTD) or, in the appraisal stage "ROCKET" to further speed up geothermal reservoir stimulation by making RJD wireline compatible. These ideas are believed to be decisive to foster safer and more competitive stimulation technology alternatives leading towards high market penetration and integral industry application.

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