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Down-the-hole Water Powered Hammer Drilling for Medium Deep Geothermal Energy Systems

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ABSTRACT

The main part of the overall energy demand in the northern European Union is due to building heating purposes. Therefore, ground-breaking techniques are needed to save energy and reduce greenhouse gas emissions especially in this low exergy sector. Especially geothermal heat storage in moderate depths is an innovative and yet barely tested concept. In difference to shallow heat storage systems, this approach upgrades the naturally available geothermal energy in the subsurface by means of external heat input and stores the heat below the general depth of aquifers used for drinking water production. This is done in summer when no space heating is required or at times when surplus energy from nearby sources is available. In winter when other sources of energy are not sufficiently and cheaply available, the thermal energy from the geothermal storage is used for heating purposes. The system of a medium deep borehole thermal energy storage (MD-BTES) consists of multiple boreholes with depths of 400 m – 1,500 m b.g.l. completed as coaxial borehole heat exchangers. The surrounding rock is utilized as heat storage, the cementation and borehole wall function as heat exchanger. Typically, water is used as heat carrier fluid. An important factor for the economic feasibility of MD-BTES systems are the drilling costs. A competitive and innovative drilling method is a prerequisite. The technique of using water instead of air as an energy carrier in down-the-hole (DTH) drill hammers has been known for years in the mining and geotechnical industry. Recent technical developments in terms of tooling and drilling fluid circulation systems enables the utilization of this drilling method for medium deep geothermal energy applications. Improved cutting transport, fast penetration rates, increased hole stability and enhanced deviation control (less than 5 to 10 % vertical deviation compared to 10 to 40 % with pneumatic hammers) are reasons for the water powered hammer drilling application. Especially a minimized deviation from the vertical is a crucial prerequisite in borehole heat exchanger (BHE) fields, where usually less than 10 m spacing between single BHEs is applied. Additionally, a reduction of CO2 emissions can be achieved since transmitting energy by water hydraulics instead of compressed air can reduce diesel consumption to only 1/3 or less. Dust is eliminated, and the drilling fluid is oil free and without grease residues. Also, no fluid additives like bentonite are necessary which allows the application of this drilling method in water protection zones. The water hammer technique has high requirements in terms of water quality. This motivates the use of a drilling fluid cleaning system for the re-use of the water. A modular drilling fluid recycling system adaptable to specific rock conditions is designed to recirculate the drilling fluid and to improve the ecological and economical footprint of medium deep drilling projects. The water powered DTH hammer drilling method can be utilized with small truck-based drill rigs and corresponding small site requirements which results in lower compatible price ranges for medium deep drilling operations compared to conventional rotary mud drilling.

1. INTRODUCTION – MEDIUM DEEP BOREHOLE THERMAL ENERGY STORAGE

The greater part of the overall energy demand in the northern European Union is related to the heating of buildings. Therefore, groundbreaking techniques are needed to save energy and reduce greenhouse gas emissions especially in this low exergy sector. The combination of different renewable energy sources – solar thermal and geothermal – with already existing district heating systems fed by combined heat and power stations (CHP) is a promising new approach to cope with the seasonal offset of thermal energy supply and demand. Especially geothermal heat storage in moderate depths is an innovative and yet barely tested concept. In difference to shallow heat storage systems (Hellström, 1991 & Bauer et al., 2010), this approach upgrades the naturally available geothermal energy in the subsurface by means of external heat input. This is done in summer when no space heating is required or at times when surplus energy from nearby sources is available. In winter when other sources of energy are not sufficiently and cheaply available, the thermal energy from the geothermal storage is used for heating purposes. The system of a medium deep borehole thermal energy storage (MD-BTES) consists of multiple boreholes with depths of 400 m – 1,500 m b.g.s completed as coaxial borehole heat exchangers (BHE) (Homuth et al. 2012 & 2013). The surrounding rock is utilized as heat storage, the cementation and borehole wall function as heat exchanger. Typically, water is used as heat carrier fluid.

For the design of a MD-BTES two separate phases have to be considered. During the charging phase hot water is injected into the BHE to heat up the reservoir. For heat extraction, cold water is pumped into the BHE in order to retrieve the stored thermal energy from the relatively hot formation. The inlet can be either the central pipe or the annulus. Flow direction and inlet temperature influence the heat transfer between working fluid and subsurface. In the charging phase, the working fluid should reach the bottom of the wellbore in the insulated inner pipe before discharging the bulk of its heat into the surrounding rock at maximum depth (Bär et al. 2015). In the extraction phase, the cold fluid should be injected into the outer pipe to utilize the borehole wall as heat exchanger surface at full length. Furthermore, this reduces heat losses of the working fluid by circulating it back to the surface through the insulated central pipe after it reached its peak temperature at the bottom of the borehole. Consequently, seasonally alternating flow directions in the BHE are beneficial (Fig. 1).

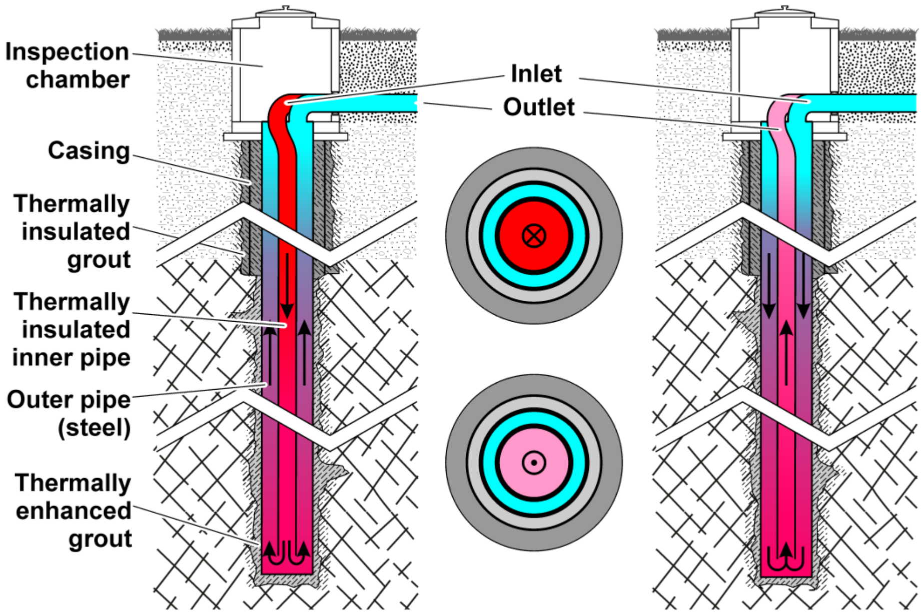

Figure 1: Schematic horizontal and vertical cross sections of a deep coaxial borehole heat exchanger used as heat storage in summer (charge of the storage as CXC flow, left side and upper middle) and winter (discharge of the storage as CXA flow, right side and lower middle), respectively. Note that only the crystalline bedrock is used as heat storage while the caprock including possible aquifers are thermally insulated (Bär et al. 2015).

For the dimensioning and operation of a BTES system, good knowledge of the petrophysical (conductive heat transfer) and the hydraulic (convective heat transfer) properties as well as of the initial subsurface temperature regime is mandatory. Additionally, important design parameters are the heat demand and the required temperature levels of the installed heating systems.

Different kinds of energy flows as well as different storage and utilization scenarios have to be assessed in the simulation and feasibility studies of such systems. Specific user profiles and economic frameworks have to be considered along with local heat sources and sinks.

The advantage of BTES systems over open systems is the closed circulation system, which is not allowing a direct contact or mass transfer of heat carrier fluids with the groundwater or subsurface. Geochemical alteration processes and a direct hydrochemical or biological influence on the groundwater will be prevented. Furthermore, this protects auxiliaries like pumps, etc. on the surface against scaling and corrosion. This results in a higher lifetime expectancy of such systems and a more constant and therefore more economical operation.

2. WATER POWERED HAMMER DRILLING

Drilling costs impact significantly on the economic feasibility of MD-BTES systems. Competitive and cheaper drilling technologies are a prerequisite. The technique of using water instead of air as an energy carrier in down-the-hole (DTH) drill hammers has been known for years in the mining and geotechnical industry. Recent technical developments in terms of tooling and drilling fluid circulation systems enables the utilization of this drilling method for medium deep (400 - 1500 m) geothermal energy applications. Experiences and results of a 413 m deep exploration drilling and geothermal borehole heat exchanger completion project in Königstein, Germany executed by Züblin Ground Engineering proved this new technological approach.

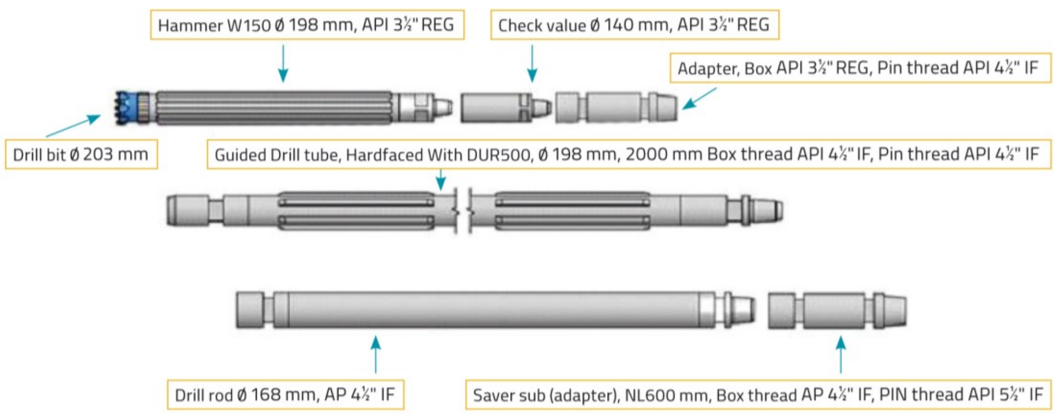

Figure 2: Bottom hole assembly of drill string for water powered hammer drilling.

The main task of the water powered DTH hammer tool is to convert the potential energy of pressurized water into an oscillating piston movement. Via mechanical impacts, the kinetic energy of the piston is transferred to the bit and finally into the rock. By rotating the bit, thereby creating new impact positions for the bit buttons, the rock will be fragmented and the fast penetration process (up to 0.9 m/min) continues. The cuttings are flushed to the outside of the drill string by outlet water from the hammer up to the ground surface along the annulus of the borehole. A typical drill string setup for geothermal borehole heat exchanger drillings is shown in figure 2. The water powered DTH hammer has some principal advantages. The water-driven hammer gives about twice as high output power compared with air-driven hammers. The main reason is the high percussion rate, resulting in a penetration rate which is two times higher than air-driven tools with 2.4 MPa working pressure. An air-hammer has a limited drilling depth in water rich rock since the normally used air-pressure of 2.4 MPa corresponds to about 240 meters of water. No theoretical depth limit exists for the water-driven hammer and the tool has successfully performed work at 4,300 meters depth. The water hammer is also more environmentally friendly. Air-driven systems require significantly more energy at the same penetration rate. This is mainly caused by the high energy losses in air compressors. Transmitting energy by water hydraulics can reduce fuel consumption to only 1/3 or even less. Dust is eliminated, and the drilling fluid is oil free and without grease residues. Also, no fluid additives like bentonite are necessary which allows the application of this drilling method in water protection zones. The water hammer technique has high requirements in terms of water quality. Fresh water is not always freely available and the water consumption of the bigger drill bits (bit diameter of 253 mm requires water flow rates of 610 l/min at 200 bar) is quite high (Fig. 3). This motivates the use of a drilling fluid cleaning system for the re-use of the water.

Figure 3: left: water hammer drill bit (203 mm diameter) in action, right: drill bit, hammer case with steering ribs and check valve.

A modular drilling fluid recycling system adaptable to specific rock conditions (crystalline or sedimentary rock) is designed to recirculate the drilling fluid (Fig. 4 & 5) and to improve the ecological and economical footprint of medium deep drilling projects. Cutting handling is thereby achieved because of the de-watering of the drilling mud via various processes like desanding, desilting, centrifugal and fluctuation treatment.

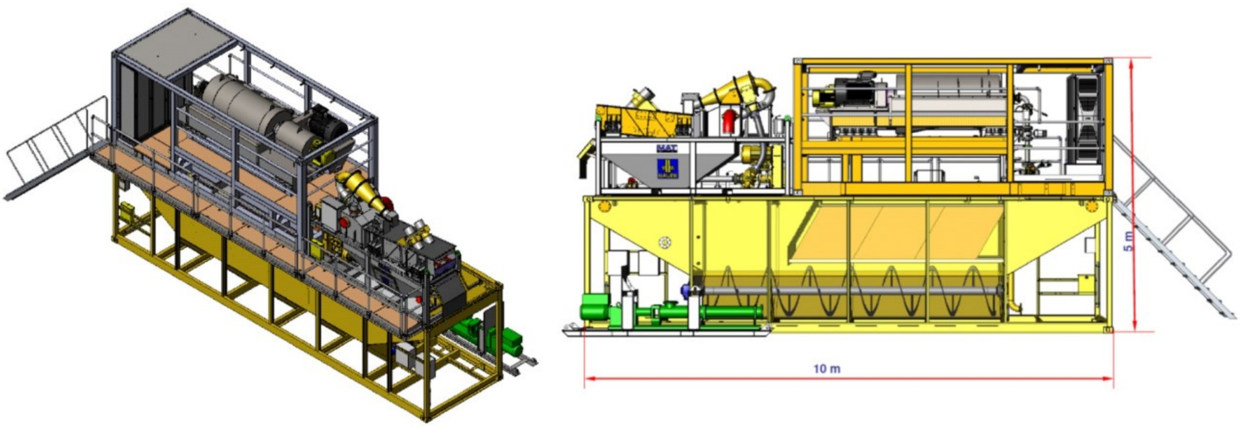

Figure 4: Designed compact modular drilling fluid handling and treatment system (© BAUER Maschinen GmbH).

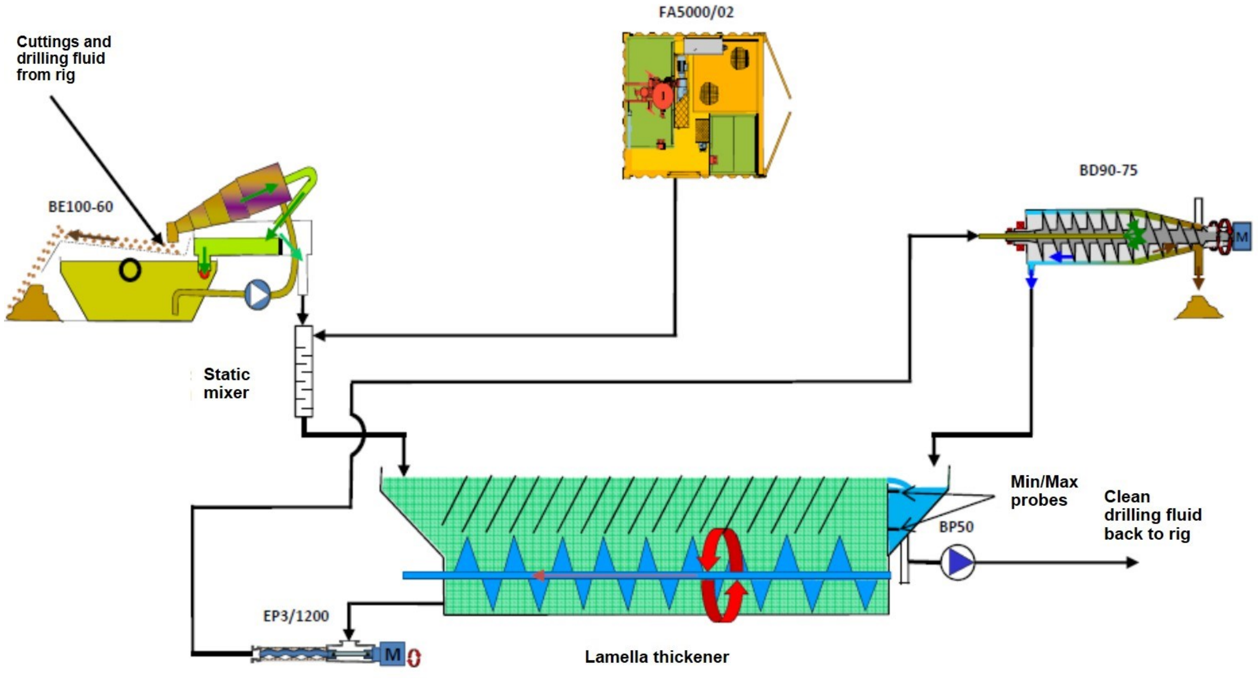

Figure 5: Flowsheet of drilling fluid handling and treatment process for down the hole water hammer drilling.

The erosion of drill pipes and hammer casing is significantly reduced when low-velocity water (0.5-1 m/s) is used as drilling fluid, instead of air with typical flow velocities between 15-30 m/s. If water is used as drilling fluid the use of close-fitting stabilizers (steering ribs, Fig. 3) is more practical. This improves the borehole straightness when compared with conventional air-hammer drilling.

2.1 Process Considerations

Deep BHEs can be constructed almost everywhere, due to the fact that neither naturally occurring thermal aquifer systems nor special geological structures are needed. The only requirement for heat storage is a location with negligible groundwater flow at reservoir depth so that the induced thermal plume is not dissipated. In contrast to conventional shallow BTES systems the mandatory heat pump is not necessarily needed due to the higher operation temperature levels (Kuntz et al., 2013). Consequently, the electric power needed to run the system is reduced and thus the profitability of the system is increased. Additionally, deep BTES have a much smaller surface footprint than shallow BTES with the same capacity and are therefore a viable option in densely urbanized areas. The completion depth of about 400 m – 1,500 m with higher underground temperatures compared to shallow systems results in a lower lateral temperature gradient between the heat carrier fluid and the surrounding rock. This means a notable decrease of heat losses, which additionally enhances system efficiency.

Charging the BTES with temperatures of up to 110 °C supplied by various heat sources in combination with greater depths can allow for return temperatures of the BTES of 45 °C – 75 °C after an initial charging phase of 3 to 5 years (Welsch et al., 2015). For the dimensioning and operation of a BTES, good knowledge of the petrophysical (conductive heat transfer) and the hydraulic (convective heat transfer) properties as well as of the initial subsurface temperature regime is mandatory (Mielke at al., 2014). Additionally, important design parameters are the heat demand and the required temperature levels of the installed heating systems.

Also because of depth considerations and geological settings (hard crystalline rocks) the boreholes for a MD-BTES shall be drilled with water powered DTH hammer drilling technology. Improved cutting transport, increased hole stability and enhanced deviation control (less than 5 to 10 % vertical deviation angle compared to 10 to 40 % with pneumatic hammer (Wittig & Bracke, 2011)) are reasons for the hydraulic hammer. Especially a minimized deviation from the vertical axis is a crucial prerequisite in BHE fields, where usually less than 10 m spacing between single BHEs is desired. A customized steering unit for DTH water powered hammers is developed to meet very high precision requirements in terms of allowable borehole deviation. This is of special interest for the drilling of borehole thermal underground storages and also for injection boreholes for icing purposes which require a minimum spacing and deviation between different boreholes. The drilling industry has great experience in that kind of works since systems for directional drilling and borehole measurements have been developed and successfully been used on several horizontal drilling projects worldwide.

3. CONCLUSIONS

The largest energy consumer in industrial countries is building infrastructure with its heating and cooling demand. Innovative energy saving concepts in this field will have the biggest impact in terms of reducing CO2 emissions. Especially the coupling of different renewable energy sources – solar thermal and geothermal – with already existing district heating systems – e.g. combined (biofuel-driven) heat and power stations (CHP) - seems to be a very promising approach to cover even the heating demand of renovated or old buildings at higher temperature levels with renewable energies. Since conventional heating systems are still installed in approximately more than 90 % of Germany's building assets, the presented concept is a viable option to reduce the heating energy demand and the related greenhouse gas emissions. Consequently, a high temperature storage and heating supply system without the application of a heat pump or specialized heat-pumps with increased coefficients of performance are needed. However, storage configurations like the MD-BTES systems can also be utilized for low temperature heating systems.

The design and completion of MD-BTES systems as described here are strongly depending on the knowledge about the subsurface and the energy flows between the heat source, the storage system and the building. The estimation of the BHE depth and completion design needs some iterative procedures. Coupled numerical-analytical modeling of the whole system combined with mathematical optimization algorithms are mandatory to estimate the optimal geometrical setup and depth of the MD-BTES.

The water powered DTH hammer drilling method can be utilized with small truck-based drill rigs and corresponding small site requirements which results in lower compatible price ranges for medium deep drilling operations compared to conventional rotary mud drilling methods. Additionally, CO2 emission reduction can be achieved since industry practice showed that for an equivalent hole of 220 m a pneumatic hammer drilling requires 2.9 l/m of diesel fuel in comparison to 0.7 l/m for the hydraulic hammer drilling process.

In conclusion, the newly developed and implemented innovative drilling technique of the water powered DTH hammer in conjunction with the new drilling fluid handling and treatment process could play a key role in the future development of medium deep geothermal energy drilling projects.

REFERENCES

Bauer, D., Marx, R., Nußbicker-Lux, J., Ochs, F., Heidemann, W., Müller-Steinhagen, H.: German central solar heating plants with seasonal heat storage; Solar Energy 84(4), (2010), 612-623.

Bär, K., Rühaak, W., Schulte, D.O., Welsch, B., Homuth, S., Sass, I.: Seasonal High Temperature Heat Storage with Medium Deep Borehole Heat Exchangers, Energy Procedia, 76, (2015), pp. 351-360.

Hellstöm, G.: Ground Heat Storage, Thermal Analysis of Storage Systems, Department of Mathematical Physics, University of Lund, (1991).

Homuth, S., Rühaak, W., Bär, K., Sass, I.: Medium Deep High Temperature Heat Storage, Proceedings of the European Geothermal Congress, Pisa, Italy (2013), ISBN 978-2-8052-0226-1.

Homuth, S., Rühaak, W., Sass, I.: Mitteltiefe kristalline Hochtemperaturspeicher – Dimensionierungsgrößen – Übertragbarkeit nördlichen Oberrheingraben (ORG), Bundesverband Geothermie e.V., Proceedings Der Geothermiekongress, Karlsruhe, Germany (2012).

Kuntz, D., Kübert, M., Walker-Hertkorn, S., Reisig, O. A.: Saisonale geothermische Wärmespeicher zur Direktheizung – ein Praxisbeispiel, Geothermische Energie 76, (2013).

Mielke, P., Bauer, D., Homuth, S., Götz, A. E., Sass, I.: Thermal effect of a borehole thermal energy store on the subsurface, Geothermal Energy, 2:5, (2014).

Welsch, B., Rühaak, W., Schulte, D.O., Bär, K., Homuth, S., Sass, I.: A Comparative Study of Medium Deep Borehole Thermal Energy Storage Systems Using Numerical Modelling, Proceedings World Geothermal Congress, Melbourne, Australia, (2015).

Wittig, V, and Bracke, R.: Innovative Hydraulic DTH Drilling Technology based on Coiled Tubing for deep, hard rock Geothermal Drilling, Proceedings European Geosciences Union (EGU) Congress, Vienna, (2011).