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SHALLOW GEOTHERMAL DRILLING

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SUMMARY/ABSTRACT

Relevant drilling methods for shallow geothermal applications are discussed, including

- *Auger drilling*
- *Ramming*
- *Rotary drilling*
- *Down-hole-hammer*
- *Top hammer*
- *Cable tool*

Indications are given for which geology and desired depth the methods are suitable.

INTRODUCTION

A drilling technology always must fulfil several demands simultaneously:

- Crushing and destruction of the rock
- Forwarding of the crushed rock to the surface or displacement into the surroundings, to create a open cavern (hollow cylinder) in the underground.
- Stabilising of the borehole wall (if not stable by nature), at least until the end of the installation and grouting work

The difficulties in drilling usually are resulting less from the forces required to destroy and crush the rock structure, but more from the problems associated with the stabilising of the borehole wall and the moving of the drill cuttings to the surface. Hence the best conditions for drilling down to 50-150 m depth are given in hard, stable rocks. In relatively soft ground with little stability, the borehole cannot be kept open without a (temporary) casing, or additives to the drilling mud.

The drilling technologies used today are discussed in this paper, together with some outlook on future options.

1 CLASSICAL DRILLING METHODS FOR GSHP

With the classical drilling methods, the basic distinction is made into percussing, rotating, and combined percussion-rotation methods. The most important of them that can be used for shallow geothermal energy are:

Auger drilling (rotating)

The drill cuttings are transported to the surface by a rotating auger (screw), cf. figure 1. Used in soft ground, diameter 63 - 350 mm, depth 15 - 20 m.

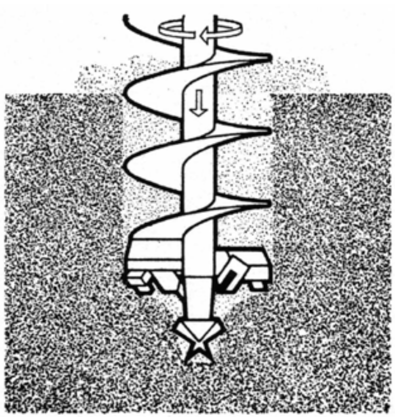

Figure 1: Schematic of an auger [Chugh, 1985]

Ramming (percussing/pressing)

In the early times of shallow geothermal, coaxial heat exchangers made from steel have been rammed directly into the underground with pneumatic devices. Because of the big problems with corrosion of the steel pipes this method cannot be recommended any more. In the Netherlands, rigs for investigations in engineering geology (Cone Penetration Test, CPT) have been modified in such a way, that they can be used for pressing plastic pipes into sandy subsurface (van den Berg, 1994). In Sweden special tools have been developed for pressing PE-pipes (in form of U-tubes) into soft clay.

Rotary drilling (rotating)

Used in medium to hard rock, the drill cuttings are carried to the surface by a drilling fluid ("mud") pumped down through the hollow drill string. Drill bits in form of wing-bits, roller bits or button bits are used to crush the rock (figure 2). Rotary drilling always is relatively slow, however, it is the only method to drill down to greater depth (several kilometres) with diameters up to about one meter. Smaller drill rigs can achieve borehole depth of 100 - 200 m with borehole diameter 89 - 300 mm. The flushing drilling method of rotary drilling is the only method that can generally be used in all kinds of rock (less or better suited), There are variations of rotary drilling, like reverse rotary, where the flow of the drilling mud is reversed (i.e. the cuttings are transported towards the surface inside the drill pipes).

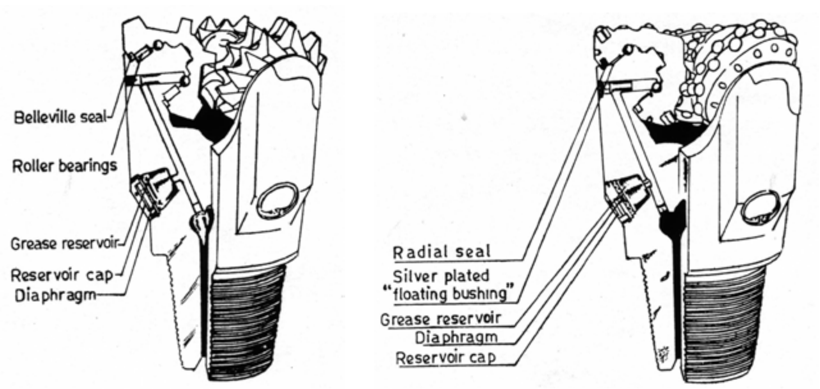

Figure 3. Example of a roller bit (left) and a button bit (right) [Chugh, 1985]

Down-hole-hammer (combined percussing/rotating)

In medium hard to very hard rock, the down-hole hammer (DTH) allows for a relatively high drilling velocity. A prerequisite is the availability of a powerful compressor, because compressed air is used for operating the hammer and for transporting the cuttings (figure 3). Diameter 101 - 216 mm, depth more than 100 m. For drilling in hard rock under softer overburden, the so-called ODEX-method has been developed, where a retractable nose at the drill bit allows for pulling the drill string out of the casing. Also hydraulically operated down-hole-hammers have been invented (G-Drill / Wassara, mainly for blasthole-drilling), but could not yet succeed in the market for BHE drilling.

Top hammer (percussing)

With this method the percussion tool is mounted on top of the drill rig, and the beats are transferred to the bit through the drill string. High velocity in very hard rock down to about 70 m depth and with 76 - 115 mm diameter; frequently used for drilling of blast holes in mines and quarries.

Cable tool (percussing)

Rather simple drill rigs with a drill bit falling to the bottom of the borehole and lifted back with a cable winch. Very slow, for shallow geothermal applications only used in developing countries.

Figure 3. Drilling with down-hole-hammer; to the left the compressor

Further methods have been investigated, but are not used commercially for thermal applications. The selection between rotary drilling and down-hole-hammer depends upon the hardness of the rock and the desired borehole diameter. The high air demand with large diameters sets a limit to the use of the down-hole hammer, while the rotary method can be used successfully in hard rock with heavy equipment only, as the crushing effect of the rotating drill bit is critical here, and requires a certain weight of the drill string. Figure 4 shows the typical range of application for both methods, while table 1 lists some relevant rock types and the suitable drilling methods.

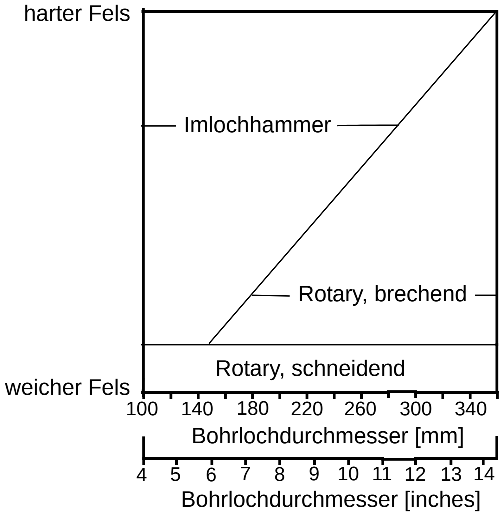

Figure 4. Typical range of application for drilling methods using rotary technology and down-hole-hammer (DTH) (after Hyttie, in [Sanner, 1992])

Attention should be taken with light drill rigs, as with most drilling methods (in particular with down-hole-hammer) the advance towards depth is the smaller problem than the subsequent lifting and recovery of the drill string. The drill rig needs to include a powerful lifting unit (typically hydraulic). The size and power of drill rigs therefore is normally given by the hook load, i.e. the weight that they are able to lift out of the borehole.

Further development of conventional drilling technology using flushing (rotary) or down-hole-hammer have resulted in drill rigs that can operate safely and efficiently under all possible underground conditions. A double power swivel and three hydraulic grips, independent from each other, allow for both the rotary method including carrying a temporary casing in unstable layers, as well as for the down-hole-hammer for fast advance in hard rock.

Table 1: Important rock types, with information on suitable drilling method for the related rock

Rock type	Typical geological age in Central Europe	Drilling method
Basalt etc.	Devonian, Permian, Tertiary	Down-hole-hammer
Dolomite	Permian, Triassic	Down-hole-hammer
Evaporites (gypsum, salt) [1]	Permian, Mid and Upper Triassic	Rotary, also locally down-hole-hammer
Granite etc	Paleozoic, Precambrian	Down-hole-hammer
Gneiss	Paleozoic, Precambrian	Down-hole-hammer
Limestone [2]	Devonian, Triassic, Jurassic, Cretac.	Down-hole-hammer, locally Rotary
Gravel [3]	Tertiary, Quarternary	Auger, gravel pump, locally Rotary
Conglomerate [4]	Permian, Triassic	Down-hole-hammer
Marl [5]	Triassic to Cretaceous	Rotary, also locally down-hole-hammer
Moraine	Quaternary	No optimum method
Sand [3]	Tertiary, Quaternary	Auger, locally Rotary
Sandstone, Greywackes [4]	Paleozoic to Tertiary	Down-hole-hammer, locally Rotary
Clay, Silt	Tertiary, Quaternary	Auger, locally Rotary
Shale, Claystone	Paleozoic, Mesozoic	Rotary, locally down-hole-hammer

[1] Problems with the use of water-based drilling mud; caution also in the presence of anhydrite (water-free $CaSO_4$), as this increases its volume when water can enter

[2] Rather different properties for hardness and thickness of layers, frequently intercalating with marls

[3] Typically problems with the stability of deeper boreholes under the groundwater level

[4] Very much varying in hardness (e.g. silification), sometimes intercalating with clay and shale

[5] Frequently intercalating with harder limestone

In rotary drilling for GSHP, mud additives (cf. table 2) are used as little as possible, as permits from the water authorities are required, and as most additives make the installation of the BHE pipes more difficult.

Table 2: Examples for additives to the drilling mud

Material	Effect	Possible problems
Bentonite	Thixotrope, stabilises the borehole in particular during standstill of drilling work	Can clog the pores of aquifers
CMC (Cellulosis)	Stabilises the borehole wall, reduces losses of drilling fluid	Fosters bacterial growth
Baryte, Ilmenite, etc	Heavy muds, are used in particular with confined / artesian groundwater conditions	Problems with installation of BHE pipes
Foams	Improve the transport of cuttings, in particular in deep boreholes with pneumatic down-hole-hammer	

2 NEW DRILLING TECHNIQUES

Within the new drilling technologies, two groups can be distinguished:

- Conventional mechanical drilling technologies in new configurations (e.g. inclined or horizontal) or with increased efficiency (e.g. hydraulic down-hole-hammer)
- Drilling methods with new technology for crushing and transport (high-pressure water, displacement, melting, etc.)

2.1 Water-driven Down-Hole-Hammer

This new method is marketed under the name Wassara (earlier a.k.a. G-Drill). The main difference to the pneumatic equipment for down-hole-hammer is the transfer of energy from the surface to the hammer through water (instead of compressed air). Fresh, filtered water with up to 180 bar pressure from a conventional high pressure piston pump is used. The water exiting from the hammer at low velocity causes little wear with drill pipes and hammer, and offers good opportunities for stable and straight boreholes. After transporting the cuttings out of the borehole, the water can be filtered and recycled (however, for protection of the hammer, fresh water should be used whenever possible).

The main advantage of the water-operated down-hole-hammer is that the driving energy is transferred to the hammer by the water, without large losses and even for deep boreholes. Furthermore, the water hammer has a percussion frequency almost double of an air-operated hammer, which is rather effective for drilling velocity in hard rock. The drill cuttings are transported to the surface even from greater depth with the water as drilling fluid.

The only relevant disadvantage is that for drilling mainly fresh water is required, and this must be filtered to a particle size of $\leq$50 m. According to data from the manufacturer, for a borehole diameter of 115 mm 7-13 m^3 of water are required each hour.

Meanwhile the Wassara-hammer is available also in diameters suitable for drilling for borehole heat exchangers. In Sweden (and also in Switzerland) the Wassara-hammer has been used successfully for BHE drillings.

2.2 Radial boreholes drilled from a manhole

Already in the 1980s borehole heat exchangers have been rammed or drilled radially from a shaft (manhole), in a pattern directed downwards at an inclined angle (e.g. the direct expansion borehole heat exchangers of the company Georg Haase from Kirchhundem, mentioned in [Sanner, 1992]). A manufacturer of drill rigs, Tracto-Technik in Altenhundem, has developed a tool for drilling such a pattern in the year 2006, with some rather intelligent solutions in details. These include e.g. the stepless control of inclination, and the fact that the modules for the motor and the actual drill rig can be detached from each other easily (figure 5).

Tracto-Technik calls the method „Geothermal Radial Drilling“ (GRD). There are some interesting advantages for this way of installation of BHE, in particular related to applicability in regions with drilling depth restrictions or narrow site conditions. A problem not to be underestimated, however, is the preferred combination of the GRD-technology with coaxial borehole heat exchangers made from pipe length and connected within the borehole using connection methods from automotive manufacturing, As this methods foresees such pipe connections also between the footpart and the head of the BHE, the method is in clear contradiction to VDI 4640, Bl. 2, item 5.2.2, where continuous pipes are demanded.

At the manifold these connections, however, are not a problem. For small installations and for drilling in existing living areas (landscaped gardens, small pathways, etc.) the GRD-method promises substantial advantages, and in combination with a BHE technology compatible with VDI 4640, and a layout of the BHE length taking into account the radial pattern, the technology can be recommended.

Figure 5. GRD-drill rig from Tracto-Technik, remotely controlled during transport (left) and ready for drilling, with drill rig detached from motor unit and positioned separately (right) (photos Tracto-Technik GmbH & Co. KG)

2.3 Unconventional Methods

Water jet drilling

Cutting of rock with a high-pressure water jet already has a history of several decades. Repeatedly drilling methods have been proposed that should use a water jet for cutting and crushing the rock. In Germany the drilling with high-pressure water jet has been further developed and tested in the beginning of the 1980s. Within the last years, the Geothermiezentrum of Bochum University of Applied Technology has taken up the idea of high-pressure water jet drilling, together with the company Vaillant GmbH & Co. KG, and has developed a usable drill rig. For this drilling method, called “Geojetting“, water under a pressure of 1000 bar and with an amount of up to 80 l/s is used (this means that by assuming a share of 60 % of actual drilling work a required water volume of almost 3 m^3/h, which is considerably lower than the values for the Wassara-hammer mentioned above). It can be assumed that also here pure fresh water, without solid particles, has to be used. The water jet destroys the rock, and is said to displace the remaining fine particles into the pores of the surrounding rock. This can well be imagined for unconsolidated deposits and sediments, but seems to be very problematic with very hard, low fracture rock. A problem with water jet drilling (as well as with other unconventional drilling methods) is the fact that no or only little drill cuttings are brought to the surface. Thus no information can be gained of the geology of the perforated layers. After much talk when the method was presented, not much application seems to have followed in the meantime. The applicability for very soft and very hard rocks has not yet safely been demonstrated, and the question of geological information from the borehole is still unanswered.

Fire jet drilling (spallation drilling)

Fire-Jet-Drilling, a.k.a. ”spallation drilling“, is known since about the mid of the 20th century, but has been a niche technology for all that time. Its effect is based upon the fact that numerous (mostly vet hard) rocks crack into small discs or chips under sudden heating (spallation). Therefore a burner chamber, supplied with oxygen and fuel oil, is installed at the drill string, creating a flame of up to 1’800 m/s velocity and temperatures up to 2400 °C. 150 l/h are named as typical fuel consumption. Water is added and injected simultaneously, which cools the burner jets and helps to move the crushed rock to the surface, together with the pressure of the combustion gases. Spallation drilling is rather demanding. It makes sense only in cases where extremely hard rock has to be drilled in, for which conventional drilling methods show almost no advance. So for instance in Jaspis-mining, drilling velocities of 12 m/h could be reported with fire jet drilling. In other rocks (e.g. limestone or basalt), no drilling advantage to speak about was achieved.

Erosional drilling

Material in the borehole is molten, partly vaporised, and displaced by electric discharge processes. This allows for the creation of non-circular holes, as a rotating action is not required. Erosional drilling is used e.g. in working with metals. The method has been also discussed for the use with rock drilling (in hard rock), but it has never been actually used, as to my knowledge. The technical effort and the energy demand should be too high, and specific advantages over other, conventional methods cannot be seen.

Melting drilling

Concerning boreholes for deep geothermal energy it has been suggested in the 1980s, to melt boreholes down into the underground with electrically heated drill bits. An advantage of this technology would be the fact that the borehole wall will solidify like a glass, and would act as support and sealing for the surrounding rock. There is no information on any practical application

3 COST OF DRILLING

The cost of drilling has remained somewhat stable, if seen in a long term. So in the 1980s, a price of about 120 DM/m (incl. a share fort he connections) was given in Germany, and about 100 SFr/m in Switzerland. In 2008, for the same amount of activity a price of about 60-70 €/m could be assessed. Around the turn of the Millenium, a slight reduction in the prides down to ca. 50 €/m could be seen, before the boom for ground source heat pumps started around 2005. There have always been offers with very low prices, in particular in Eastern Germany. Typically this was the case when a driller urgently needed a job to be done (even with prices not or only hardly covering the cost for the company), or there were massive shortcomings in quality and material.

For Switzerland, there is a study of FWS, that did investigate the cost for smaller ground source heat pumps; a slight cost reduction can be seen here, even with the nominal prices (figure 6).

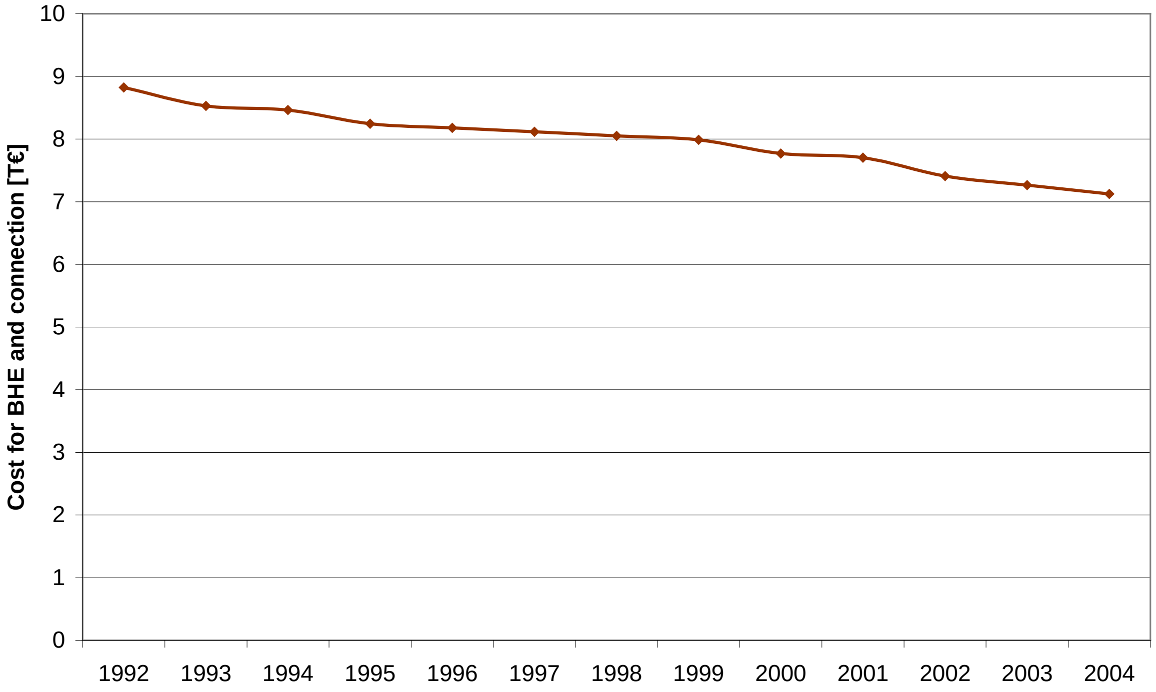

Figure 6. Development of nominal cost for borehole heat exchangers and connnection in Switzerland, calculated for heat pumps with 7.6 kW heating capacity (after data of FWS; exchange rate SFr-€ of Oct. 08)

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