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GEOTRAINET TRAINING MANUAL

FOR

DRILLERS SHALLOW GEOTHERMAL SYSTEMS

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Geo-Education for a sustainable geothermal heating and cooling market

Project: IEE/07/581/S12.499061

GEOTRAINET TRAINING MANUAL FOR DRILLERS OF SHALLOW GEOTHERMAL SYSTEMS

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Section A: Introduction

CHAPTER 1

OVERVIEW OF SHALLOW GEOTHERMAL SYSTEMS

By Burkhard Sanner

1. INTRODUCTION

Geothermal energy, in the public's perception, is often associated with volcanoes and geysers. However, beside these spectacular manifestations, there is also a more modest side of geothermal energy. The geothermal heat flow from the deeper crust to the surface normally cannot be felt by human beings, although it reaches about 40 TW of thermal output, eventually radiated into outer space. On the way down into the deeper layers of our planet, temperature rises by 3 K per 100 m of depth on average, with a doubling or tripling of this rate at geothermal anomalies.

A clear definition for geothermal energy was badly needed both for the technical as well as for the administrative and regulatory side of geothermal energy use. Based upon German practice, the European Geothermal Energy Council (EGEC) adopted a definition giving only the surface of the solid earth as a boundary for geothermal. Since July 2009, this definition is for the first time stated in the EU legislative framework; EU Directive 2009/28/EC on Promotion of Renewable Energy Sources reads:

> Art. 2:
>
> The following definitions also apply:
>
> (c) "geothermal energy" means energy stored in form of heat beneath the surface of solid earth.

The distinction between shallow and deep geothermal is not fixed. Historically a depth of ca. 400 m is used, going back to a Swiss support scheme from the 1980s. In general, shallow geothermal systems can be considered as those not pursuing the higher temperatures typically found only at greater depth, but applying technical solutions to make use of the relatively low temperatures offered in the uppermost 100 m or more of the Earth´s crust. In North America, shallow geothermal technology is also known under the term "geoexchange".

For shallow geothermal, the undisturbed ground temperature that forms the basis of heat extraction or heat injection varies between <2 °C and >20 °C, depending upon the climatic condition of the region and the depth of the borehole.

To use the constant, low temperatures of the ground, there are two options:

- Increase or decrease the temperature of geothermal heat to a usable level using heat pumps (Ground Source Heat Pumps, GSHP)
- (Underground Thermal Energy Storage, UTES).

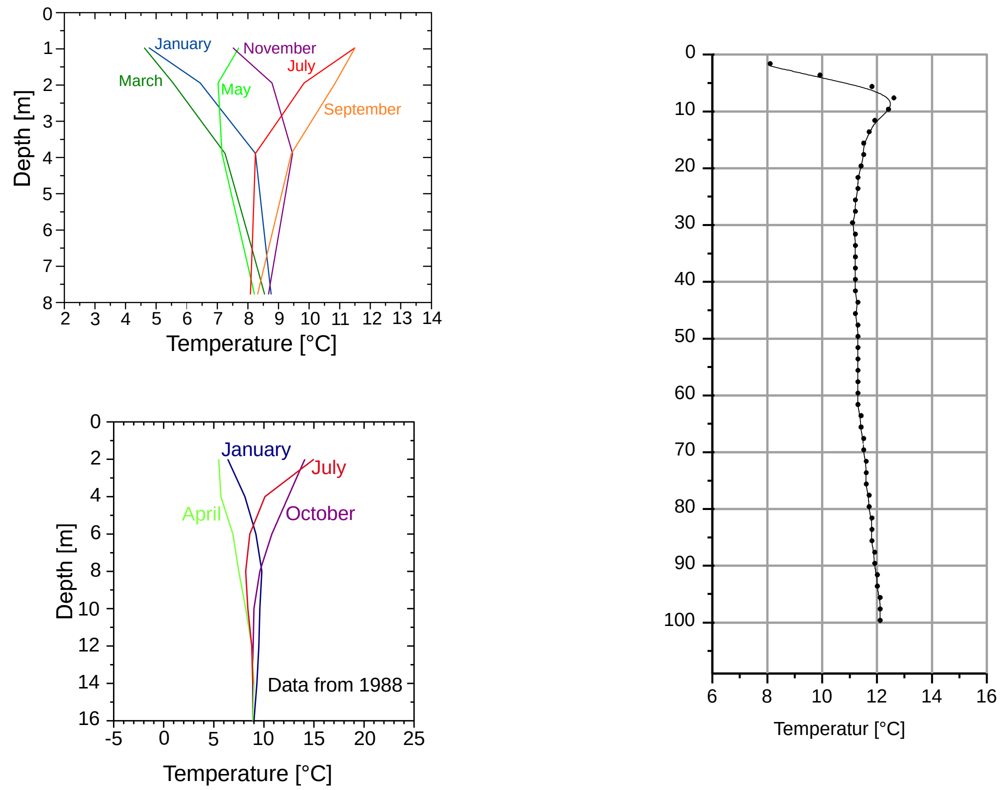

Figure 1. Constant temperature in the “Neutral Zone” at 10-20 m depth development, and temperature development down to 100 m depth (anticlockwise from top left):

measured at Royal Edinburgh Observatory, average 1838-1854 (after data from Everett, 1860);

measured at the Borehole Heat Exchanger field test station Schwalbach, Germany;

before a TRT in Germany, 2007 (courtesy of UBeG GbR)

The various shallow geothermal methods to transfer heat out of or into the ground comprise:

- Horizontal ground heat exchangers 1.2 - 2.0 m depth (horizontal loops)
- borehole heat exchangers 10 - 250 m depth (vertical loops)
- energy piles 5 - 45 m depth
- ground water wells 4 - >50 m depth
- water from mines and tunnels

Methods using a heat exchanger inside the ground are also called “closed” systems, methods producing water from the ground and having a heat exchanger (e.g. the evaporator) above ground are called “open” systems. Schematics of these methods are shown in Figure 2 and some advantages and disadvantages of closed and open systems are listed in Table 1.

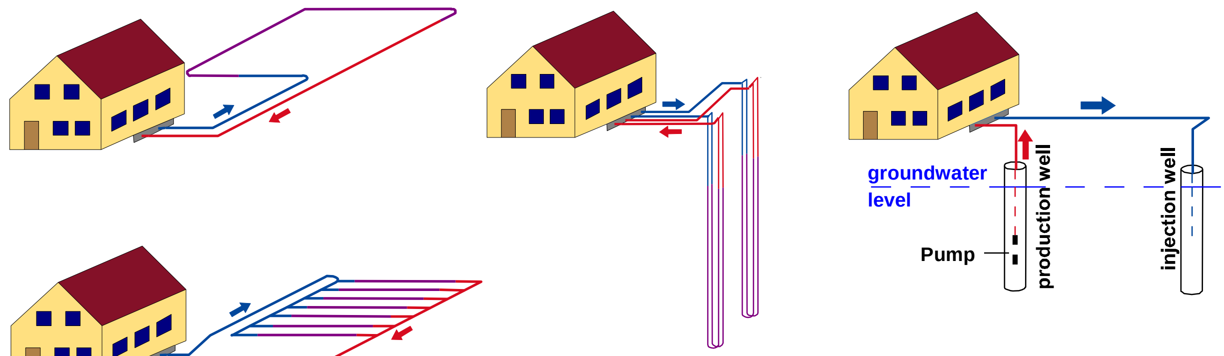

Figure 2. Schematic diagram of the most common ground-coupling methods (from left): horizontal loops, BHE (vertical loops), and groundwater wells

Groundwater wells	Borehole Heat Exchangers (BHE)
Heat transport from ground to well or vice versa by pressure difference (pumping)	Heat transport from ground to BHE or vice versa by temperature difference
Advantage: high capacity with relatively low cost relatively high temperature level of heat source / low level of cold source	Advantage: no regular maintenance safe can be used virtually everywhere
Disadvantage: maintenance of well(s) requires aquifer with sufficient yield water chemistry needs to be investigated	Disadvantage: limited capacity per borehole relatively low temperature level of heat source / high level of cold source

Table 1. Basic heat transport criteria and advantages/disadvantages associated with open or closed systems

While Figure 2 shows the exterior form of different ground coupling options, Figure 3 details the internal arrangements possible for closed shallow geothermal systems. They differ in the type of heat carrier medium inside the ground circuit, and in the way this circuit is coupled to the heat pump refrigeration cycle. The most common set-up is the use of a fluid as heat carrier (typically water with the addition of an antifreeze agent), which is circulated through the ground loop by pumping.

Direct expansion systems are characterized by the extension of the refrigeration cycle into the ground loop, i.e. the heat carrier is the working medium of the heat pump, and a two-phase-flow (liquid/steam) occurs inside the ground loop. In practice, direct expansion (DX) has been applied successfully to GSHP with horizontal loop, while the combination with vertical loops resulted in problems with compressor oil return, etc. The advantage of DX lies in the absence of a circulation pump and of heat exchange losses between ground circuit and refrigeration circuit;

however, some of the power for circulating the refrigerant through the ground loop has to be provided by the heat pump compressor.

Heat pipes make use of a two-phase system inside a single, vertical pipe. The working medium with low boiling point is evaporated by the Earth's heat in the lower section of the pipe. The resulting steam rises to the top of the pipe due to its lower density, and transfers the heat to the refrigeration circuit via a heat exchanger. The steam thus cools down and condenses again, flowing back in liquid form on the pipe wall towards the bottom of the pipe. While both the brine systems and the DX systems can be used both for heating and cooling, the heat pipe is suitable for heating purposes only, as no heat can be transported down into the ground (the driving force is provided by gravity, which works only in one direction).

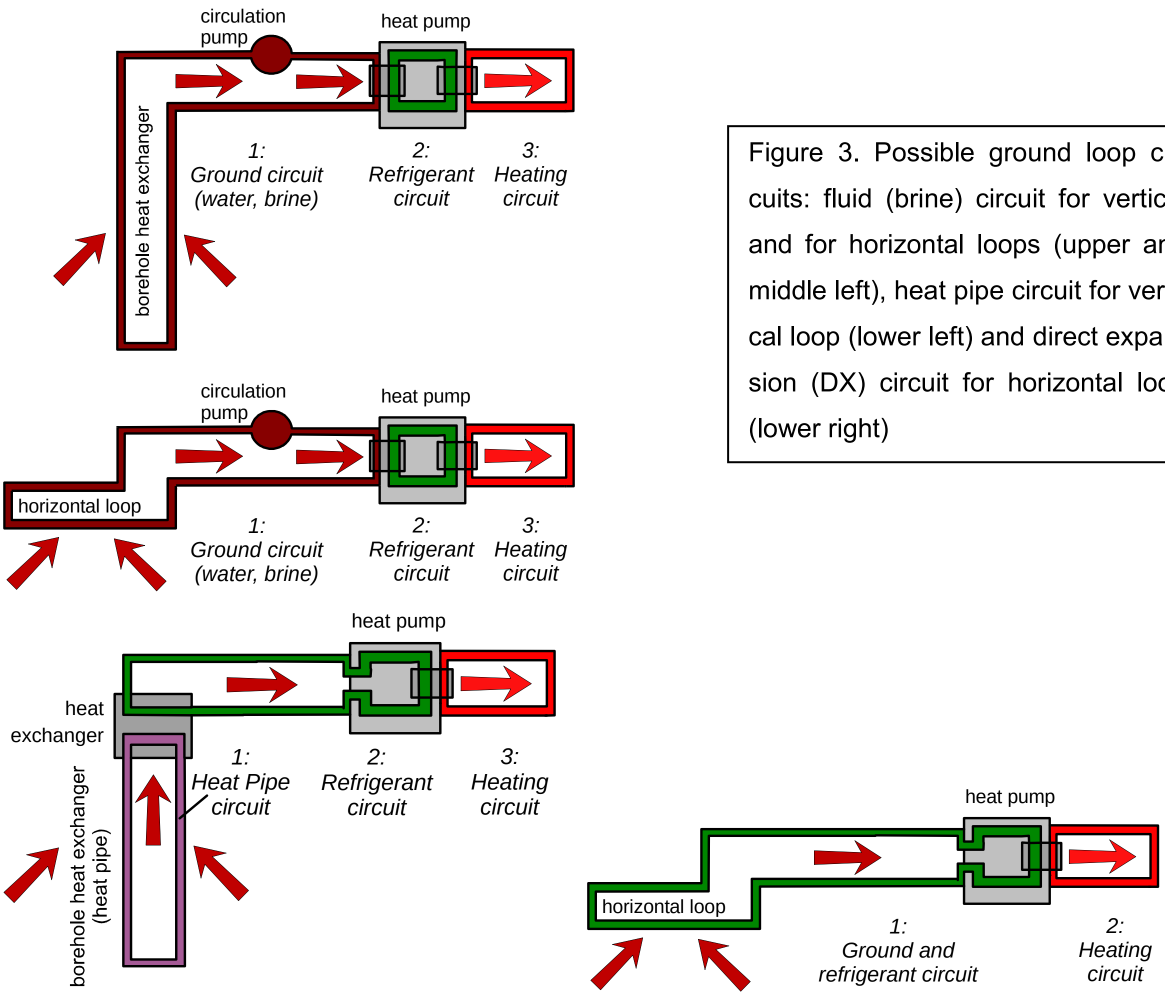

Figure 3. Possible ground loop circuits: fluid (brine) circuit for vertical and for horizontal loops (upper and middle left), heat pipe circuit for vertical loop (lower left) and direct expansion (DX) circuit for horizontal loop (lower right)

The earliest example for GSHP in literature dates from 1945 in Indianapolis, USA, and concerns a DX system with horizontal loops (Crandall, 1945). Already in 1947 an article by Kemler presented all the basic GSHP configurations we use today. In Europe (Austria, Germany, Sweden, Switzerland) the first GSHP with groundwater wells and the first horizontal loops appeared around 1970, and the first BHE before 1980.

After a short boom in these countries around 1980, associated with the second oil price crisis, the development in Europe was slow throughout the 1980s and 1990s, with the exception of

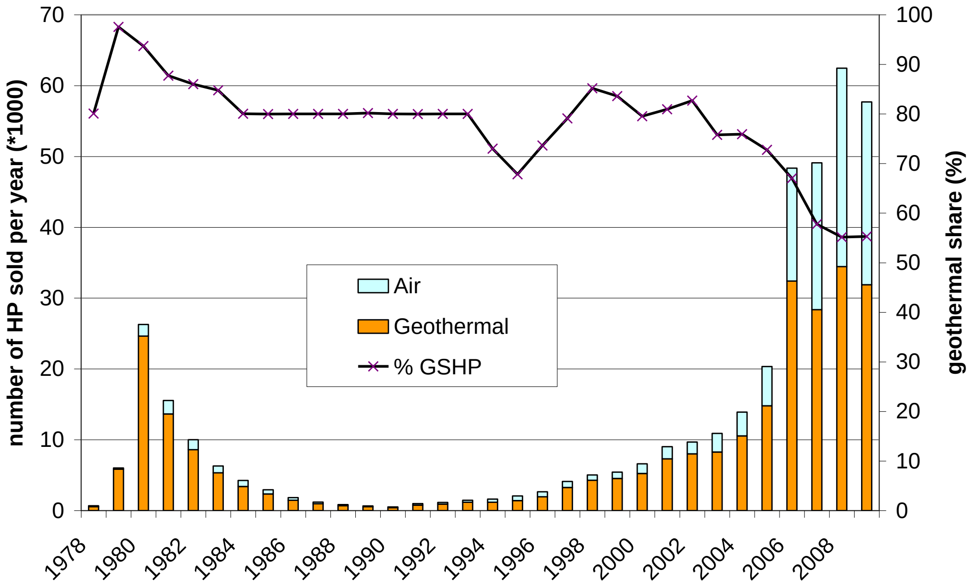

Figure 4. Development of heat pump sales in Germany (after data from BWP and GtV-BV)

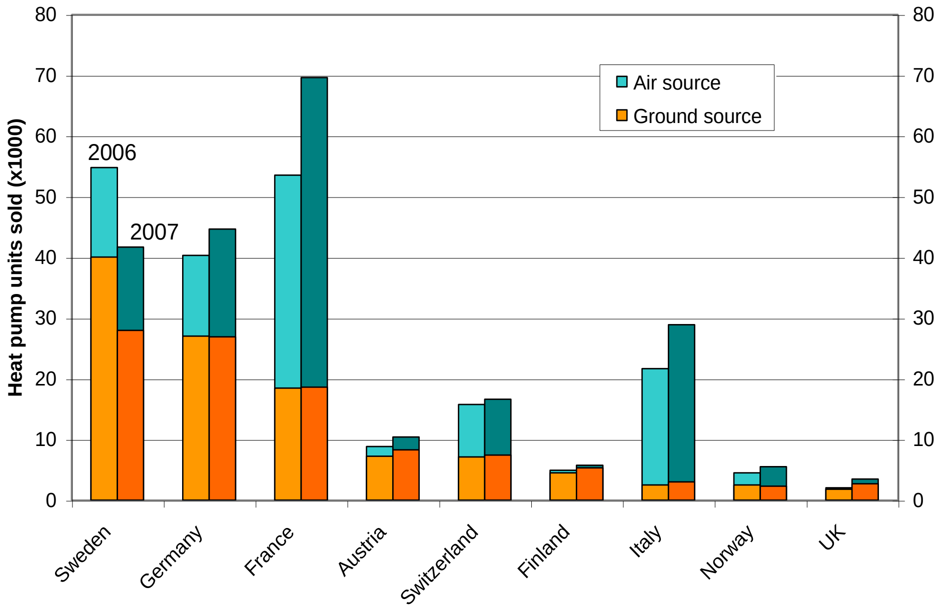

Figure 5. Heat pump sales for 2006 and 2007 in some European countries (after data from EHPA)

Sweden and Switzerland. Since about 2000 a strong market development can be seen in Germany (Fig. 4), followed by France, and now in 2010 the GSHP technology has spread to all EU countries. Figure 5 shows the heat pump units sold in some European countries in 2006 and in 2007, giving a high share for GSHP in colder regions, and a majority for air-source heat pumps in warmer lands (France, Italy).

All material for GSHP today is available from manufacturers, in proven quality: pre-fabricated BHE, grouting material, pipes, manifolds, heat pumps (Fig. 6). Methods for determining the ground parameters (thermal and hydraulic) are available (Fig. 7), design rules and calculation methods have been developed, and guidelines and standards set the frame for reliable and durable installations.

Figure 6. Examples of products for GSHP: pre-fabricated BHE, tested and delivered to the drilling site (Photos left: Haka, centre: Rehau)

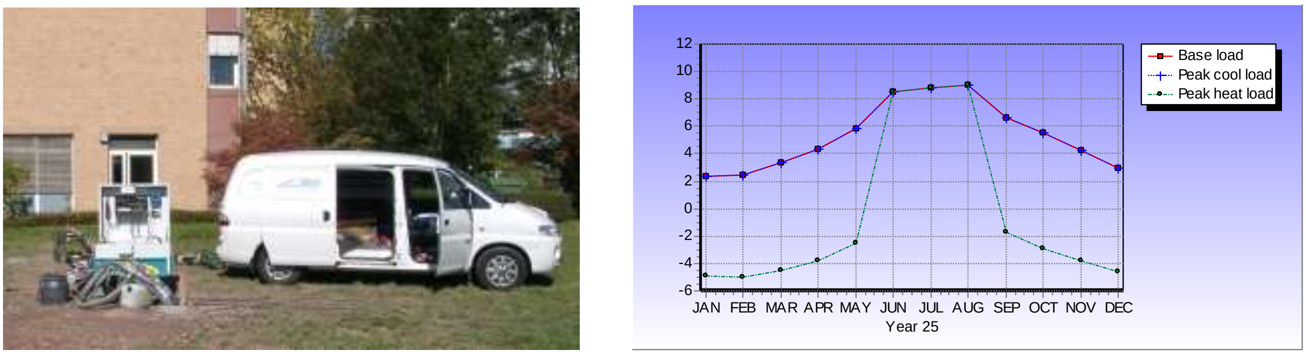

Figure 7. Example of Thermal Response Test for determining ground parameters (left) and calculation of BHE layout using EED software (right)

A useful tool for comparing different installations of BHE is the specific heat extraction rate. This is the maximum thermal capacity at the heat pump evaporator (refrigeration capacity), divided by the total length of BHE, given in Watt per Meter BHE length (W/m). In the early years of BHE in Europe around 1980, a value of 50 W/m was given as a standard value for Germany, and 55 W/m for Switzerland. These values were used for design of residential GSHP at that time – and 50 W/m is still used as a crude rule of thumb for many smaller installations today! However, the actual specific heat extraction possible in a certain project depends strongly upon ground conditions (thermal conductivity), system requirements (operating hours), system size (number and distance of BHE, interference), etc. (Sanner, 1999). So a BHE system never should be designed following a rule of 50 W/m of heat extraction, and the specific heat extraction value only used for comparison *after* a thorough design calculation has been made.

In recent times, claims by manufacturers of some new BHE types have been made for achieving specific heat extraction values of more than 100 W/m (apparently independent of any thermal properties of the underground). Using a simple consideration allows the viability of such claims to be checked.

The heat transport in a BHE system can be divided into two stages:

- the transport in the undisturbed ground around the borehole (controlled mainly by the thermal conductivity of the ground k)
- the transport from the borehole wall into the fluid inside the pipes, controlled by the type of grouting, the pipe material, the borehole and pipe geometry, etc., and given as a summary parameter r_b (borehole thermal resistance).

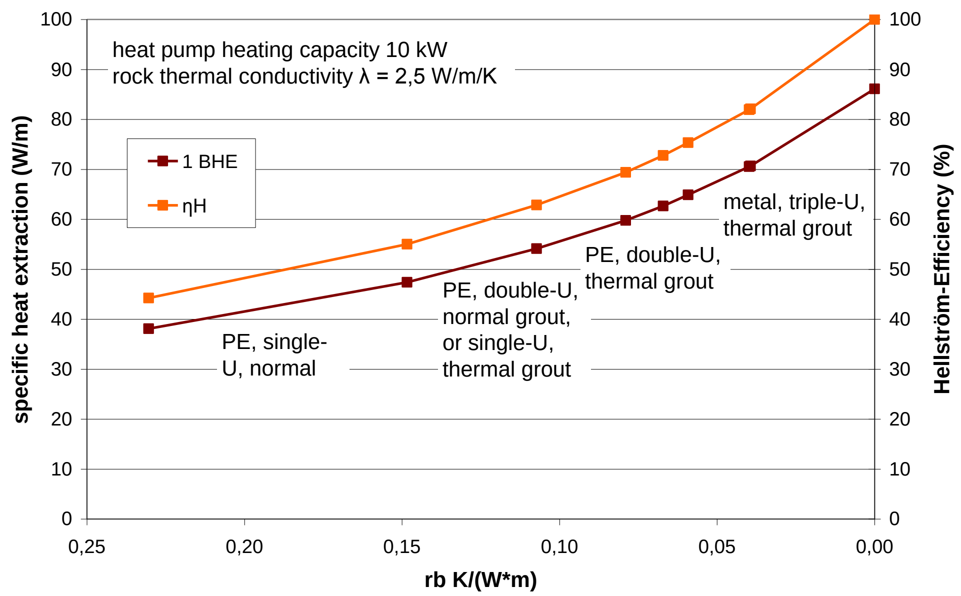

Figure 8. Specific heat extraction rates (brown curve) and Hellström-Efficiencies (orange curve) as a function of borehole resistance of different BHE types in a typical single-family house under average ground conditions; with the chosen parameters, the maximum heat extraction rate at a theoretical maximum η_H = 100 cannot exceed ca. 85 W/m

The specific heat extraction rate of a BHE can only be calculated for a certain installation, taking into account all the parameters mentioned above. A new design of BHE claiming an improvement can only influence the parameters inside the borehole, resulting in a lower value for r_b. The best BHE would be a system with r_b = 0 K(W/m), i.e. a spontaneous heat transfer between borehole wall and fluid. This can be achieved only theoretically, but can act as a benchmark for determining the efficiency of an actual BHE system. This efficiency is called Hellström-Efficiency and is given as:

η_H = sustainable heat extraction possible in a certain project/heat extraction with r_b = 0 where: η_H = 100 for the theoretical maximum (Fig. 8).

2. FURTHER INFORMATION

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Section A

CHAPTER 2

LIMITATIONS

By Olof Andersson

1. INTRODUCTION

As is shown in the previous chapter, there are several different shallow geothermal systems available on the commercial market. These are, in short, ground source heat pumps (GSHP) for extraction of heat (and cold), and underground thermal energy storage (UTES) for active storage of heat and/or cold. This chapter considers the potential of these systems as well as limiting conditions when it comes to apply them in practice.

The potential is in many ways related to local or site specific conditions, not only climate and geology, but also the sector of application. The latter may be family houses, commercial and institutional buildings, district heating and cooling systems, or even industrial facilities. These all represent very different size and load characteristics in the design of a geothermal system.

The limitations can be looked upon as the outer boundary conditions that lead to a go or a no-go for project concept. They can be physical, such as climate and geological circumstances, but may also be connected to other site conditions, for example ground availability or other interests for ground use. Country specific, there are also a lot of other potential limitations. These could be of a social, cultural or political nature, but more often economical or legal. However, these limitations are flexible and may disqualify one type of system, but allow another. It is of great importance that all potential limitations are considered early (at the feasibility stage) in any project.

2. WHY SHOULD DESIGNERS AND DRILLERS CARE ABOUT A PROPER FEASIBILITY STUDY?

Properly done, any GSHP project should start up with a feasibility study. The reason for this is to create a basis for decision on how the project should be further developed. In this stage the project plan should be checked against all types of technical, economical, legal and environmental constraints that may affect the design and finalization. If a designer or a driller is not aware of the constraints and limitations, then there is a risk that a GSHP concept may turn out to be not feasible, at a late stage. This will of course lead to a dead investment for the customer and unnecessary claims on anybody involved in the realization of the plant. It may also seriously damage the reputation of and confidence for these types of systems, something that has to be avoided.

3. POTENTIAL ASPECTS

The two main renewable heat (or cold) extractions from shallow-lying geological strata are shown in Figure 1. Solar energy is the driving force of the hydrological cycle and indeed for processes that are the basis for traditional renewable energy, such as hydropower, wind and biomass.

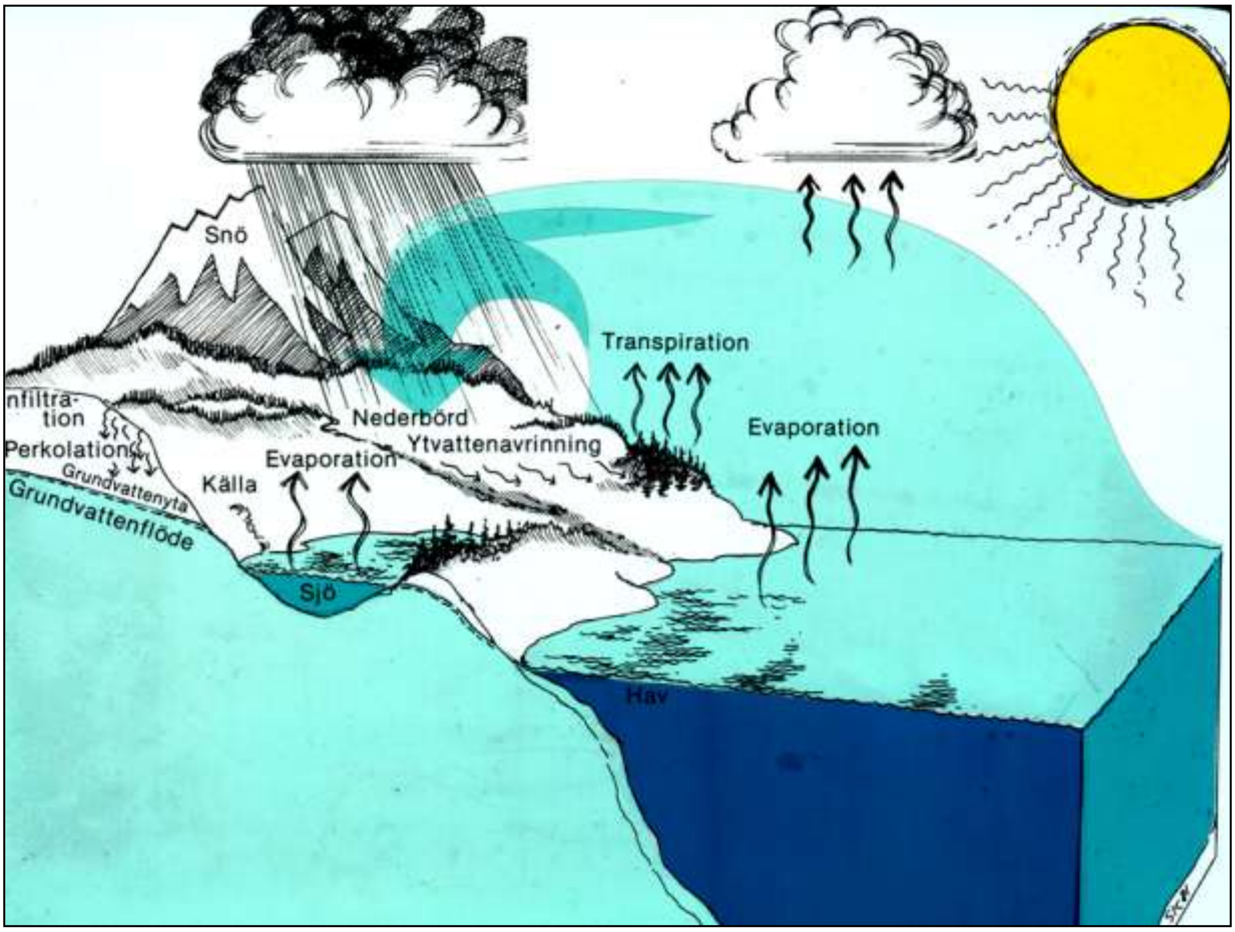

Figure 1. In the hydrological cycle all traditional renewable energy sources can be found. The geothermal heat flow is another renewable source

The average solar radiation that is adsorbed by the ground is in the order of 1500 kWh/m^2 annually, while the geothermal heat flow is restricted to some 0.6 kWh/m^2. In practice, this means that the major portion of extracted heat from the shallow underground is derived from solar energy, rather than geothermal heat from below. This basic knowledge, on how heat transfer in the underground works, suggests that shallow geothermal applications can be regarded as solar energy. For this reason the potential is huge and almost unlimited. However, putting single closed loop vertical systems too close to each other will lead to continuous chill down of the underground. Depending on geological and climate conditions and how much energy is extracted, the “safe” distance varies between 20 and 30 m. Under normal conditions, the temperature at a depth of approximately 10 m reflects the average temperature in the air (+14.3 on average). However, at places with snow in the winter, the ground temperature will be a few degrees higher since the snow will insulate the surface. At greater depths, the ground temperature will increase due to thermal heat flow. This flow creates a geothermal gradient that on average is around 3 °C/100 m. In countries with old crystalline rocks, the gradient is often much less, while countries with clayey rocks have a higher gradient. The heat flow represents around 0.07 W/m^2. However, the variation is rather large and depends greatly on geographical position and local geological conditions.

4. LIMITATIONS AND BOUNDARIES

4 1. Technical limitations

It has been shown in the preceding section that the natural sources for GSHP systems (atmospheric and geothermal energy) are practically unlimited taking into consideration that plants are not located too close to each other. In general, the source is always there and from a technical point of view there are no limitations in using it.

For systems using the underground for seasonal (or sometimes short-term) storage of heat and cold, the source of energy for storage may be different. Such a source is for example waste heat from industrial process cooling. Another may be waste cold from heat pump evaporators. These types of sources always have technical limitations such as load, duration, temperatures, availability, etc. that are site specific. These limits should of course be established in an early stage of a given project.

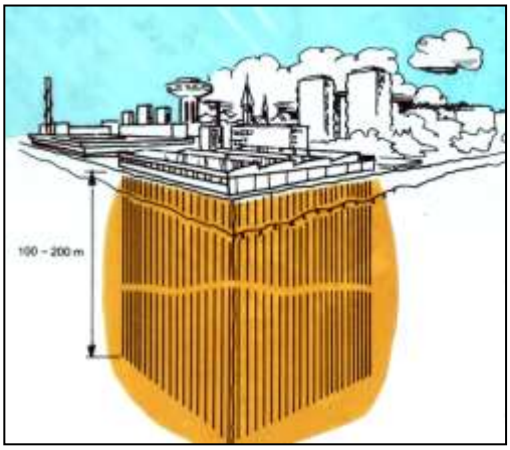

Figure 2. Technical limitations for an underground storage project may have technical limitations related to load characteristics, working temperatures, availability of energy source, etc. It is of importance to define these limitations at an early stage of the project

4.2. Geological limitations

In principle, one or several types of GSHP systems are technically feasible in any type of geology. It is more a matter of finding a proper construction method, related to the special geological conditions at the site for installation. Still, the geological requirements differ according to what type of system is to be installed, summarized in the following general statements.

- ***Closed loop systems*** are in general applicable in all types of geology. However, thermal properties and drilling problems may be a limiting factor

- ***Open systems*** (based on pumping ground water) require a geology containing one or several aquifers. Still, aquifer geometry, hydraulic properties and water chemistry may be limiting factors on any site.

4. 3. Hydrogeological limitations

The hydrogeological conditions would in practice govern the design of any open loop system. Inputs, such as type of aquifer, geometry, groundwater level and gradient, textural composition, hydraulic properties and boundaries are in fact essential for the design and realization of such systems. For closed loop systems these parameters are of less importance, but can in some cases constitute limiting conditions.

- ***Closed loop systems*** may be affected by flow of ground water. For systems with heat extraction, this is normally an advantage. For systems with storage of heat and cold (BTES), it may be a disadvantage for cold extraction. Furthermore, a low groundwater level will limit the extraction of heat and cold if no backfilling is used

Aquifers used for open systems may have a limited yield (well capacity) and/or an unfavourable chemical composition. It may also be that the size and geometry is not suitable. Furthermore, the aquifer may already be occupied by, for example, supply of drinking water. This will be a limiting factor that cannot be overcome. During such circumstances a closed loop system may or should be considered as an alternative.

4. 4. Climate conditions

Climate plays an important role in the application of GSHP systems. There are many reasons for this, but one essential condition is that the ambient temperature of the ground is reflected by the average temperature in the air. The type of climate (tropical, arid, Mediterranean, maritime and continental) will also limit the usage of some systems (Table 1).

Climate type	Weather condi-tions	GSHP systems	
		GSHP	UTES
Tropical	Hot, no seasons	Not feasible	Not feasible
Arid	Hot, cool nights	Not feasible	Storage of cold night - day
Mediterranean	Warm Summer	Occasionally feasi-ble	Seasonal storage heat and cold
Marine	Warm Summer	Feasible	Seasonal storage heat and cold
Continental	Warm Summer	Very feasible	Seasonal storage heat and cold

Table 1. Principal feasibility for GSHP systems in different climate

Another climate factor is the humidity. In hot climates with a high humidity, there will be temperature requirement for cooling that allows condensation. In practice this means that it is not possible to directly cool a building from the ground. However, in such a case there are other technical solutions.

As indicated in Table 1, the best performance of UTES systems are linked to continental climate conditions with a seasonal swing of temperatures from summer to winter. Such conditions may also exist locally at unexpected locations, (see the example in Figure 3).

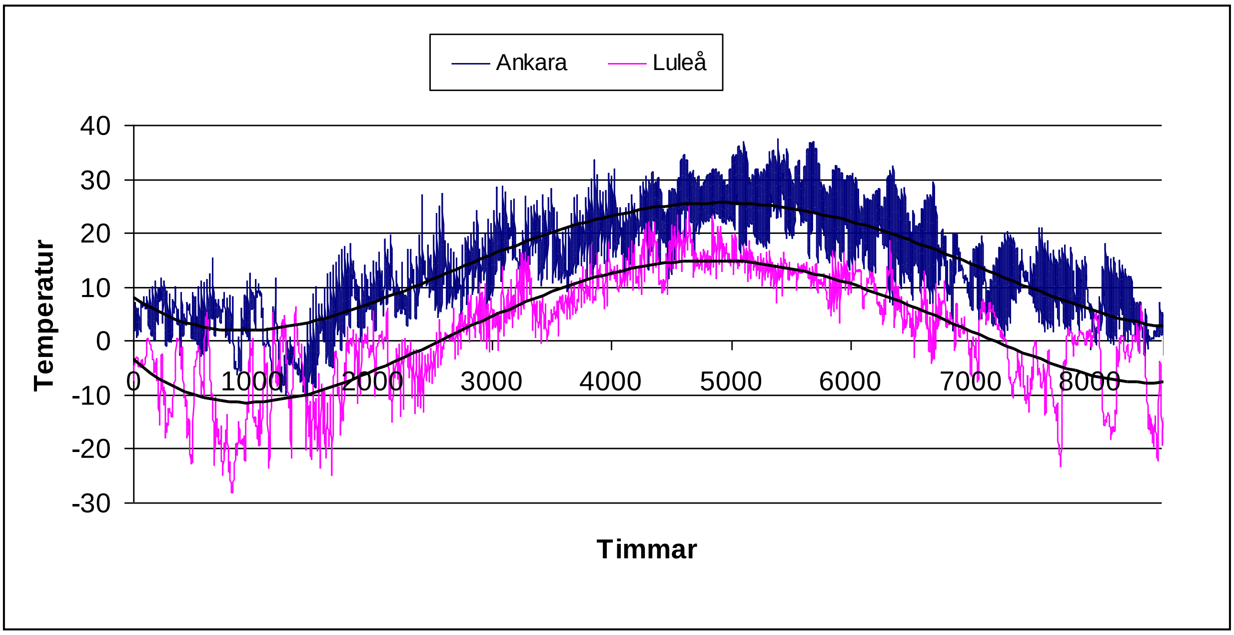

Figure 3. The climate conditions for using UTES are almost equivalent in Luleå (north Sweden) and Ankara (Turkey)

4.5. Environmental limitations

GSHP energy systems will in general contribute to less global emission of carbon dioxide and other harmful environmental substances. However, country specific, and maybe also locally, there may be limiting concerns such as:

- Contamination of the ground and the ground water by boreholes connecting to the surface, boreholes shortcutting different aquifers and the usage of anti-freeze
- Change of the underground temperature that may affect the chemistry and bacterial composition and growth in the underground
- Emissions, damages and local disturbances (noise, etc.) caused by drilling and construction
- Damage to buildings, fauna and flora operating the systems.

In most countries, these types of limitations are the subject for legislation. The outcome from permit applications may sometimes be that a GSHP scheme is denied by legal courts or local authorities.

In general, open loop systems are more difficult to have approved than closed loop systems. The reason is that using groundwater causes more concerns in most countries.

4. 6. Economical limitations

In most cases, GSHP systems on the commercial market should be profitable. However, in the R&D stage, unprofitable installations can be realized as well as systems that meet environmental goals. In such cases, favourable funding will in many cases limit a less favourable economic outcome from the system. Still, from a strict commercial point of view, the cost limits can be explained as:

- The operational and maintenance costs combined must be less than for competitive systems

- The additional investment cost for the GSHP system has to be paid back by the value of saved energy and maintenance cost within the technical life time of the system

The calculated straight pay back time varies between different sectors and different countries, but commonly 10-15 years are judged as a reasonable upper limit.

4.7. Legislation as a limiting factor

Legislation incorporates a complex mixture of laws, codes, standards and norms. Specifically, such regulations are more frequent in countries that already commonly use GSHP systems. In other countries there may be very limited and a type of “wild west” situation on the regulation side. This situation creates a limiting factor in itself, since the authorities do not know how to react on permit applications. Indeed, this sometimes causes good schemes to never develop further.

At this stage it seems as if the legislators do not know how to evaluate GSHP systems from a hazard point of view. Therefore, to create functional legislation in different countries, the legislator has to be more aware, informed and possibly also trained on how GSHP systems work and what they represent.

Section B: General Topics

CHAPTER 3

SHALLOW GEOTHERMAL CONFIGURATIONS AND APPLICATIONS

By *Olof Andersson*

1. Introduction

Shallow geothermal systems are mainly based on using low – moderate temperatures for heating and cooling. These temperatures are naturally found in the upper geological layers and will mostly be in the same order as the average out-doors temperature seen over a year, see further in chapter 2. Using these temperatures in geothermal system is referred to a direct use, mainly for serving as a source of heat for heat pump applications. It may also be directly used for comfort and process cooling, especially in colder climate zones.

A second group of shallow geothermal systems are Underground Thermal Energy Storage systems, known as UTES systems. In these cases thermal energy is seasonally or diurnal stored in the underground. This means a changed of temperature to be lower or higher than the natural. In order to minimize energy losses from the storage, these systems will normally be applied larger projects. In most cases these systems will be designed for both heating and cooling, even if there are some applications for either storage of heat or cold.

In this chapter an overview of optional systems is given as a basis for decision in an early stage of any shallow geothermal application.

2. Why should drillers and installers care about different shallow geothermal systems

Any geothermal installation, disregarding the size and geographical place, will normally be optional when it comes to choice of system. The decision of system will always be governed by site specific conditions such as load demands, geological and hydrogeological conditions, regulations, space and economics. If a driller is not aware of optional systems, then there is a risk that a geothermal concept may not be properly applied and in worst case cause damages to the market development of shallow geothermal systems.

3. Classification of Shallow geothermal systems

Depending on the development in different countries worldwide but also different research groups the nomenclature of the systems is somewhat different. The terms “open” and “closed loop” systems are originated from the USA, and may be looked upon as practical descriptions of systems with boreholes with plastic pipes (closed) and systems where groundwater is pumped from and injected through water wells (open). These terms are also used in Europe, but here some country specific terms are also contributing to the terminology as will be shown further down.

The systems for storage of heat and cold in the underground (UTES) has mainly been developed within the frame of International Energy Agency (IEA), the Implementing Agreement Energy Conservation through Energy Storage (ECES) as a result of more than 20 years of research and development. Also these systems can be described as closed and open loop systems. In figure 1 expressions used for shallow geothermal systems are given. It also shows the Swedish terms for each system (translated to English). The figure also suggest that systems used for heat extraction commonly refer to the term GSHP (Ground Source Heat Pumps) that is commonly used in heat pump statistics to separate these from heat pumps using air as a heat source.

Systems for heat extraction (GSHP)
"Groundwater Heat" (Open loop)
"Rock Heat" (Closed vertical loop)
"Topsoil Heat" (Closed horizontal loop)

Systems for extraction of cold (Direct Cooling)
"Groundwater cooling" (Open loop)
"Rock cooling" (Closed loop)

Underground Thermal Energy Storage (UTES)
"Aquifer storage", ATES (Open loop)
"Borehole storage", BTES (Closed loop)
"Cavern storage", CTES (not applicable)

Fig.1. Expressions and terms for common shallow geothermal systems divided into direct extraction systems and systems for active storage.

Chapter 3

4. Overview of systems for direct energy extraction

4.1 Closed vertical loop (rock heat system)

This system applied for single resident buildings consist of one or several boreholes in which borehole heat exchangers (BHE) are installed. The boreholes may commonly be up to 200 m deep and drilled into almost any type of soil and rock. The BHE is connected to a heat pump. By circulating a heat carrier fluid (water mixed with antifreeze), heat is extracted from the borehole surroundings and transferred to the heat pump from which heat at a higher temperature is distributed to the building.

During the winter season the temperature of the fluid and the borehole surroundings will gradually get lower. The fluid will then often reach a temperature well below the freezing point. As a result the COP of the heat pump will gradually drop. However, in a correctly designed system the temperature will not be as low as making the heat pump to stop. This is as a matter in fact a great advantage of GSHP:s compared to air as heat source.

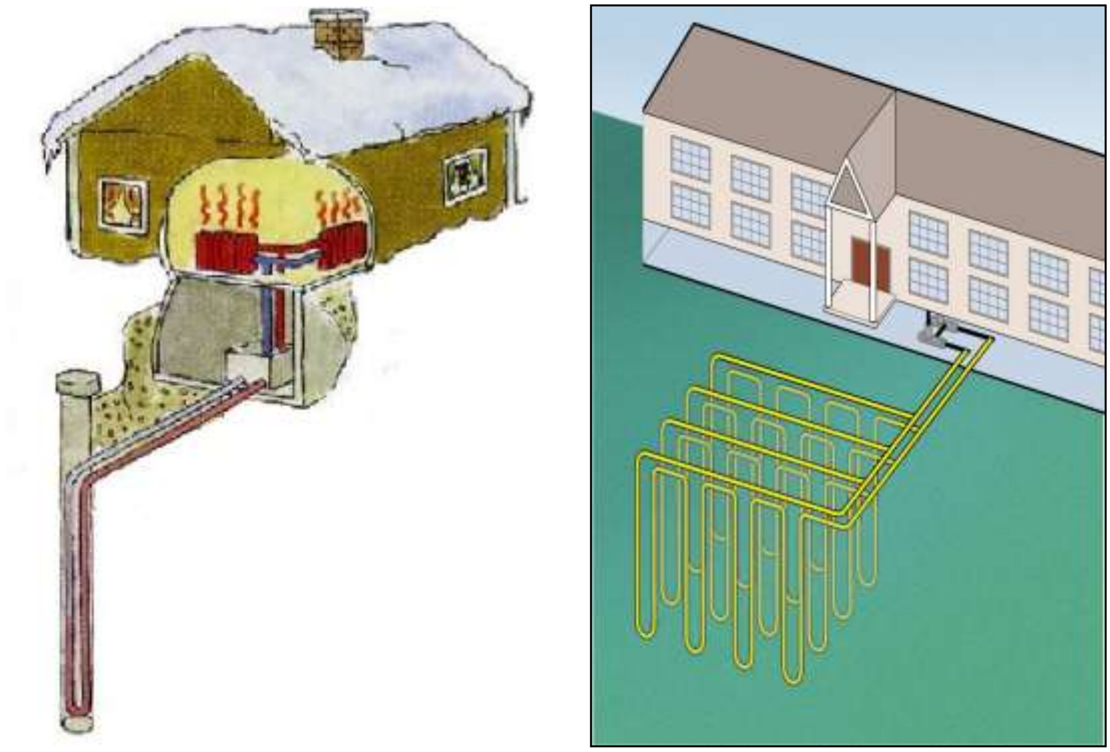

Fig.2. Vertical closed loops applied for a single and a multifamily residential building

In the summer, these systems may provide free cooling directly or the heat pump operates as a cooling machine and stores condenser heat in the ground. This is of cause a great advantage, especially in warmer climates. By definition, using the system also for cooling, transfer it into a BTES system, see next section.

If the system is used for heat extraction only, which is the most common practice in colder climates, a single borehole recover its normal temperature naturally during the summer season. If several boreholes are used it is of great importance that the boreholes are not to close to one each other. If not, the natural recovery will not function properly and the temperature of the boreholes will gradually decrease over the years.

From a geological point of view, the best efficiency of vertical loops is obtained in crystalline rocks with a high content of silica, such as granites and gneisses. Among the sedimentary rocks the best efficiency is achieved in quartzite and dense sandstones with a low porosity. However, it is important to know that almost any types of rocks are technically feasible, as well as any types of soil. This makes the vertical loops having a very high potential regardless the geological conditions at site.

Vertical systems can also be used for direct cooling, especially for comfort cooling during the summer season. In these cases heat is disposed into the boreholes and the rock mass is then naturally regenerated during the winter season. In Sweden, such rock cooling is mainly used within the telecom industry supplying some 35 TV broad casting masts and approx. 25 switchboard stations with free cooling.

4.2 Closed loop horizontal systems

The shallowest system is the horizontal loop. This consists of a plastic pipe that is typically ploughed or dug down in the garden of a residential house as shown in figure 3. Such a system may not be of interest for a driller, but may still be considered by an installer as an option to vertical loops.

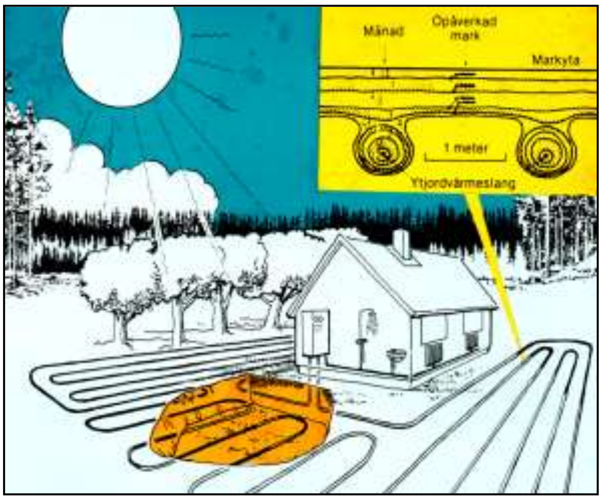

Fig.3. The horizontal loop system that requires large open space to be applied

Compared to vertical loops this system takes a less investment to construct. On the other hand it is somewhat less efficient due to a lower working temperature of the fluid. This is partly due to the relatively less thermal conductivity of the soil compared to a rock. Furthermore, the technique is based on freezing the moisture in the soil that requires a rather low fluid temperature over a long part of the winter season. The freezing process will continuously draw water towards the pipe, hence creating ice scaling around the plastic pipes. The ice itself will have a positive effect on the thermal conductivity. Since the frost is melting rather quickly in spring, these systems are not suitable for any type of cooling.

Normally the pipes are placed approx.1 meter below the surface with a distance of 1 m between the pipes. However, in later years a more compact system has been developed called “slinky”. These consist of coils of plastic pipes, that are placed vertical in dug ditches, one at each wall of the ditch.

The best efficiency of horizontal systems is obtained in fine grained types of soil with a high content of water, such as clay and silt, while dray gravel and sand should be avoided.

4.3 Open loop systems (groundwater systems)

Ground water is a valuable natural source especially for drinking water. Still, using ground water for energy extraction is fairly common in many countries for both heating and cooling. The reason for this is that groundwater systems are more efficient than closed loop systems. This is based on the fact that the temperature of groundwater is practically constant all over the years (if pumped from a depth of 10 meter or more) and that water is the very best carrier of thermal energy (the highest heat capacity).



Fig.4. Groundwater is an excellent source for both heating and cooling

As illustrated in figure 4, the technology "normal" groundwater wells are used for energy extraction. However, to create a system with extraction and injection is more challenging. Such systems have to be circulated under pressure and under perfectly airtight conditions to avoid problems with clogging and corrosion induced by chemical processes. It is also common to use a heat exchanger to separate the groundwater loop from the heat pump loop (see upper right in the figure).The term "open loop" system is therefore very misleading since the circulation of groundwater in such a system also has to be under "closed" conditions.

For small scaled applications (5-10 kW) on the country side, a single well or even a dug wells may be used. In these cases the chilled water is disposed to surface water or infiltrated by a buried stone bed.

For larger systems doublet wells have normally to be used, one or several for production and approx. an equal number of wells for reinjection of chilled water (environmental and legal issue each country).

The production well is equipped with a submersible pump with a riser pipe and a cable passing through a perfectly tight lid. The pump should be placed well below the lowest draw down level. For larger systems the pump may be frequency controlled. It is also an advantage to have a pressure recorder in the well to keep track of the drawdown.

The injection well is typically equipped with a pipe ending well below the ground water level. The lid should be perfectly tight and have a valve for ventilation.

The ground water loop has to be perfectly tight and preferably be put under pressure at all times (to decrease the potential for corrosion and clogging).

During winter the water is pumped either to a heat exchanger (recommended) or directly to the evaporator of HP (may cause corrosion and clogging problems). Typically the temperature is lowered with some 4-5 ^{o}C.

The chilled water being injected may cause a thermal break through by time if the distance between the wells is not long enough. A thermal break through between narrow wells may be compensated by injection of heat during summer. However such measures will turn the system into an ATES system, see further down.

Groundwater can also be used for direct cooling. The efficiency of such cooling is normally very high and is therefore of great interest. The maximum temperature requirements would typically be some 10^{o}C for comfort cooling and some 25^{o}C for process cooling.

5. Overview of systems for underground thermal energy storage (UTES)

5.1 Background

Traditionally thermal energy is stored in big steel tanks for short term applications. By using the underground as a storage medium a long term (seasonal) storage has proven to be feasible. The development of these systems started in the early 80: ties within the frame of IEA. A large number of concepts were tested of which Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES) has been developed to a commercial level in a number of countries.

These systems have proven to be both technical and economical feasible and are now applied to a variety of commercial and institutional buildings all over the world. They are mainly used for combined heating and cooling, but in some cases they are also used for storage of heat or cold only.

The main concept is to store natural heat from summer to be used for space heating during winter as one function, and by reversing the system to store winter cold to be used for cooling during the summer, see figure 5.

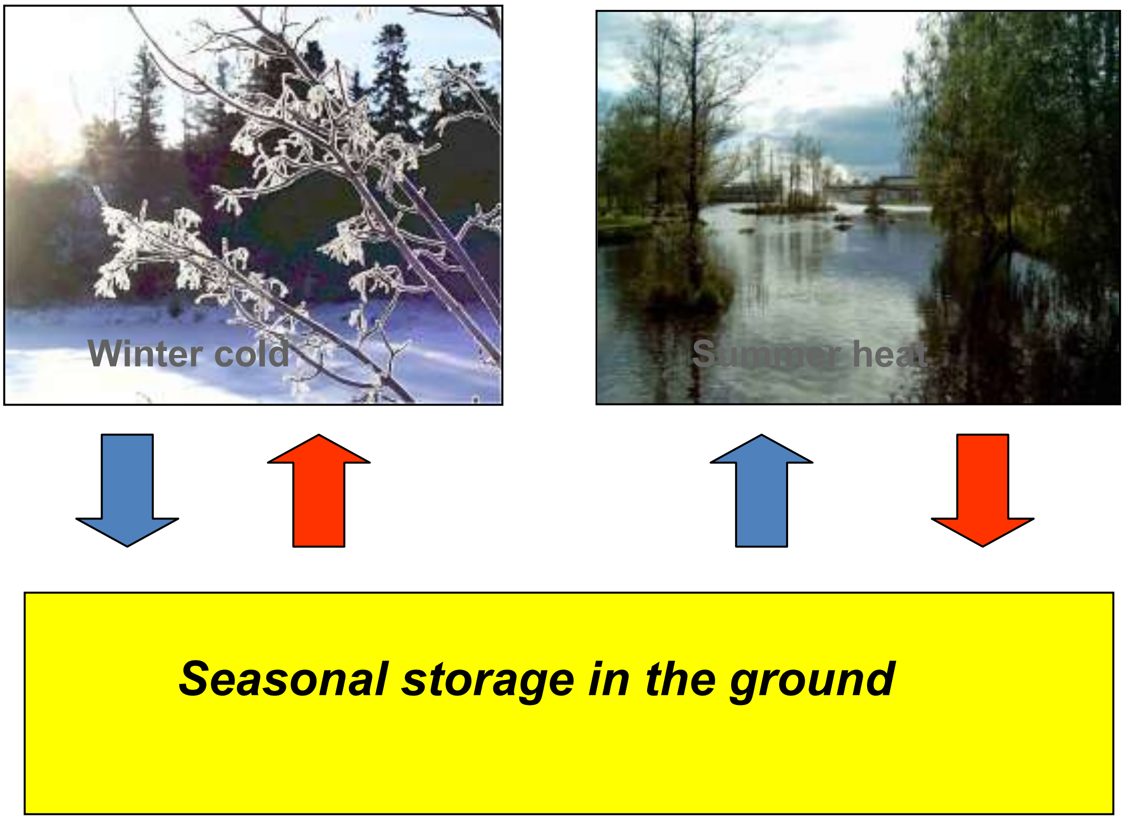

Fig.5. Concept for seasonal storage of natural heat and cold in the underground.

5.2 Aquifer storage (ATES)

An aquifer consists of a geological layer that not only contains groundwater, but also has the property to yield the groundwater to a well that penetrates the layer. The degree of yield (well capacity) is related to the permeability (hydraulic conductivity) of the aquifer that will vary significantly at different sites. Most aquifers are formed by porous sediments, such as a layer of sand or a not so consolidated sandstone, but some aquifers are more related to fracture systems in harder rock types.

The porosity and or fracture systems will act as a type of very efficient heat exchanger against the solid part of the aquifer. Hence, the groundwater will, as it flows in system, heat up or chill down the solids and in this way create a more or less homogenous temperature in the aquifer. In this sense such storage will have a high thermal efficiency.

By dividing an aquifer into one warm and cold part, heat and cold can be separately stored. This is of case a great advantage for applications where cooling is an essential part of a energy requirement.

The principal system for an ATES application for both heating and cooling is shown in figure 6. As can be seen from the figure, the storage is connected to a heat pump loop and to a centralized system for cooling. Typically the system will change its flow direction twice a year, spring and autumn.

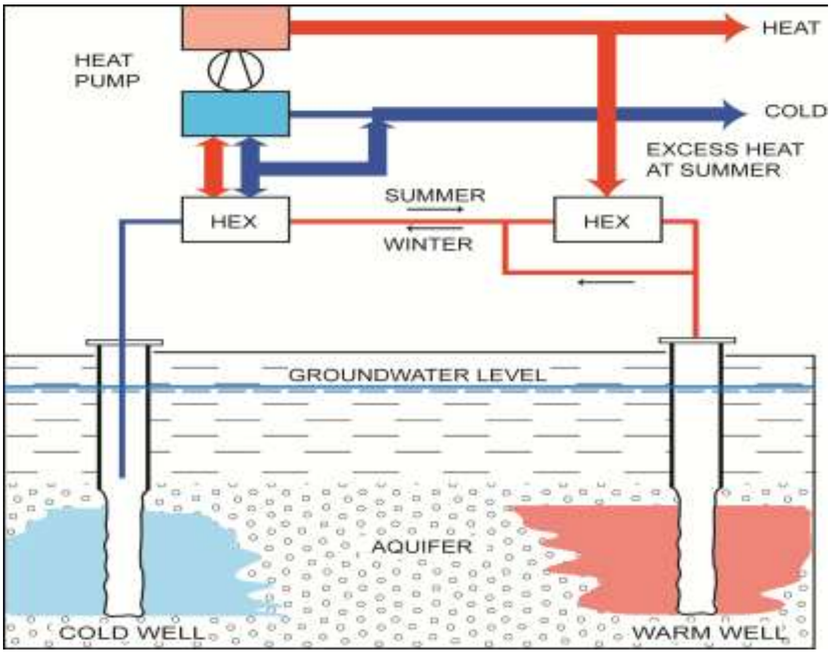

Fig.6. Principal flow chart of an ATES system for heating and cooling

A system designed for combined heating and cooling will typically cover 50-70 % of the heating load and 100 % of the cooling load. However, if a cooling peak is needed, the heat pump will produce this cold. The waste heat from the condenser is then stored at the warm side of the aquifer.

Typical temperatures are 5-8oC on the cold side and 13-16oC on the warm side. For a system applied in a moderate climate zone, the system will work with seasonal performance factor (SPF) of 6-8.

There are also some ATES configurations that are working directly against a ventilation system without a heat pump. A late example of that is the Stockholm Arlanda airport, where cold and heat is stored in an esker (a shallow ridge formed aquifer). In this case the warm side is used during the winter to preheat the ventilation air and for melting snow at gates. The warm water is then chilled down to approx. 4-5oC which is the temperature stored at the cold side of the aquifer. This cold is then used for comfort cooling of the airport. The system is designed for a load capacity of 6 MW with a turn over of some 20 GWh of heat and cold. The maximum flow rate of ground water is 200 l/s produced by five wells on the cold side and six wells on warm side.

Another ATES application used in Sweden is storing of cold only, both on seasonal and short-term basis. The cold is normally obtained from surface water at a temperature just above the freezing point. These systems are most often connected to district cooling systems. One short term storage example on such an application is an ATES plant placed in an esker in the City of Stockholm. This storage is run with a capacity of 15 MW of cooling load and contains 12 high capacity wells.

5.3 Borehole storage (BTES)

Borehole storage consists of a number of densely placed boreholes in which borehole heat exchangers (BHE) are installed and connected to form a closed loop system. The boreholes will together serve as a gigantic heat exchanger with the soil and rock penetrated by the holes. By circulating a fluid with higher or lower temperature than the natural in the underground through the BHE, thermal energy is stored or extracted from the borehole surroundings. Since the boreholes are closely spaced they will influence each other. Therefore the whole rock mass within the borehole field will affected by the temperature induced change. The higher thermal conductivity the rock has, the faster will the heat or cold be transmitted. Because of the large storage volume that in this way is created the heat or cold will stay in the storage for a long time making it possible to generate seasonal storage.

The most common BTES system is designed to produce both heat and cold. The principal configuration for such a system is shown in figure 7. The figure is also showing a concept for process cooling, in this case a telecom station.

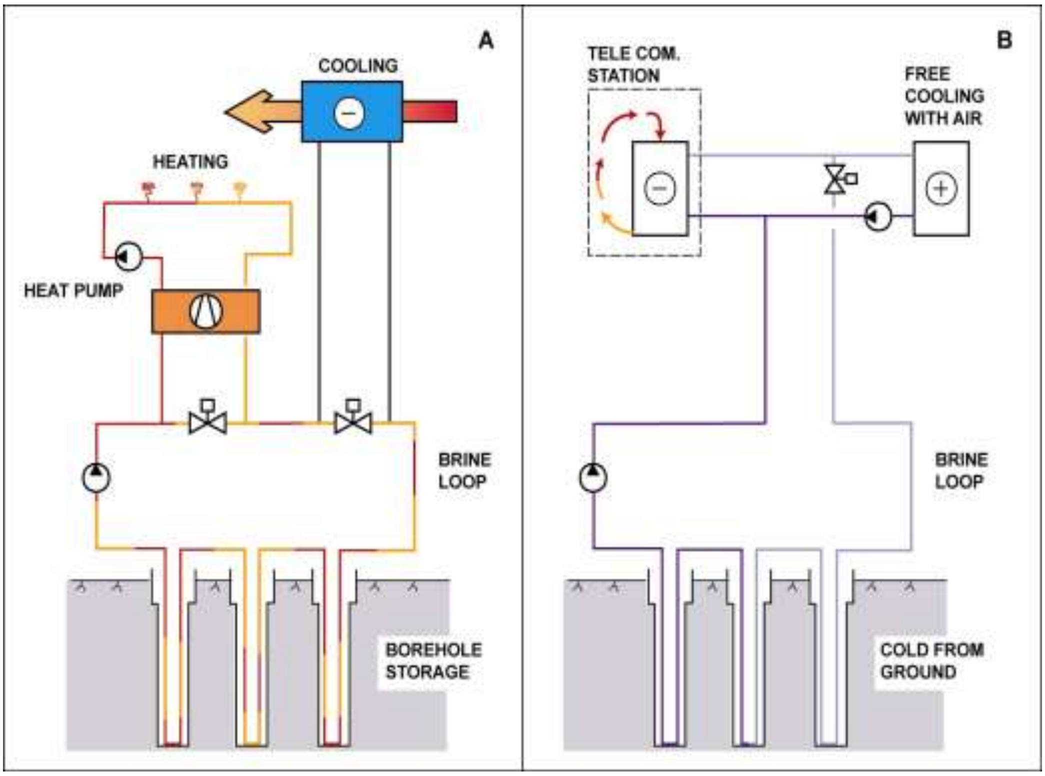

Fig.7. Principal system for combined heating and comfort cooling (A) and for process cooling (B)

The heat pump supported system with combined heating and cooling is typically applied for all sorts of commercial and intuitional buildings such as offices, schools, hospitals, stores, churches and different kinds of administration buildings.

During the winter season heat is extracted from the rock mass. The temperature of the storage will then gradually decrease well below the natural temperature. During the summer season the chilled rock will serve as free source of cold and extracting that will lead to a thermal recovery of the rock. However, the stored cold may not be enough to cover the demand. In this case the heat pump will be used as chiller to cover peak loads. This type of system is typical for cold or moderate climates and is commonly used in northern Europe and goes by the name “European design”.

If the cold demand is as high as the heat demand, or even higher, there is a system where all cold is produced by the heat pump. This design goes under the name “American design”. The condenser heat is in this case stored underground. This means that the rock will be heated up well above the natural temperature at the end of summer. Due to the high storage temperature, running the heat pump in the upcoming winter will be more efficient than in the “European design” that works with low temperature storage. On the other hand, a large portion of cold is freely generated in “European design”.

Independent type of design these systems work with moderate storage temperatures and commonly with a SPF in the range of 5-6.

Compared to ATES the BTES systems may be less efficient. However, a BTES system properly constructed will have no, or a minimum of maintenance. It will also have a long technical life and will be easy to operate. They are applicable almost anywhere, but they may not be very easy to install under certain geological conditions. To chose drilling methods and drilling depth is therefore an important aspect when these systems are implemented.

From a regulation point of view, it is fairly simple to have a permit for BTES systems. Still, a key question is how to avoid contamination of the underground and the groundwater. For the time being many countries regulates a proper backfill of the boreholes. Other countries, preferably Scandinavian, allow boreholes only filled with groundwater in most of the cases.

Further information

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CHAPTER 4

Boundary conditions for UTES applications

By *Olof Andersson*

1. Introduction

A complete shallow geothermal system contains not only one or several boreholes or wells. The system also involves the connection to indoor installations such as heat pumps and heat exchangers, tubing and fittings, power supply and controlling system. This more or less complex system is designed to produce heat and/or cold to a certain building, or set of buildings. It may also involve the distribution of heat and cold, but this is commonly a subject for other construction parties.

A drilling company may be asked to bid on a total system or only parts of such a system. In any case there will be a number of boundary conditions related to responsibility that have to be considered. Essential such boundaries are:

- Contractual boundaries, in the sense of scope of work for the drilling contractor.
- System boundaries, meaning technical limits for shallow geothermal applications, such as requirements on loads, temperatures, flow rates and system pressure.
- Natural boundary conditions, such as climate and, not at least, geological conditions at a given site
- Boundaries related to economical, environmental and regulation aspects.

2. Why should drillers and installers care about different boundaries

A drilling or installation company must be aware of that the construction of a shallow geothermal system may be a complex task considering the contractual responsibilities involved. From a technical point of view he also has to consider the functional expectations of the system parts he is constructing. Commonly a contractor also has to consider or take the full responsibility for environmental and permit issues. Finally, in large scale projects it is expected that the contractor will coordinate his work with other contractors at site.

3. Contractual and technical boundaries

The form of contract will be described in the tender documents. The options are a “turn key” contract, handing over the functional responsibility over to the contractor, or a contract where the customer is responsible fort he design. As shown in figure 1, the scope-of-work boundary commonly is placed either outside the building (green line) or covering the total plant for heat and cold production (red lines).

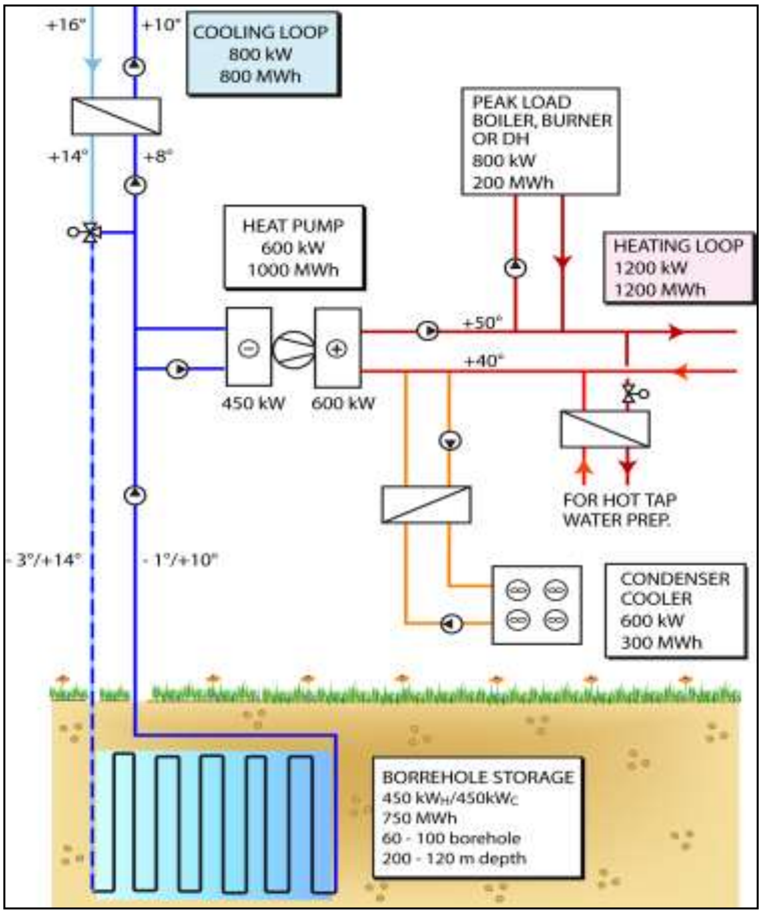


Fig.1. Examples of different contractual boundaries' for a BTES system

As easily can be understood, the choice of boundary will play an important role not only for the value of the contract, but also for the functional responsibilities connected to the contract.

For a BTES system as shown in figure 1, there are also some technical boundaries to consider. One is that the plastic pipes (PE) will expand or shrinking due to the fluid temperature. An upper temperature limit of fluid is not to exceed a temperature of +20°C. At higher temperatures the strength of the plastic will gradually decrease. A lower limit would be governed by the content of antifreeze in the brine for grouted boreholes, and the lowest evaporator temperature allowed for the heat pump. For non grouted boreholes freezing of the water in the borehole is another lower temperature boundary. This will occur at an approx. average fluid temperature of -4°C if a single U-pipe is used.

Another technical boundary in BTES systems is the applied flow rate. The upper and lower limits are related to a number of circumstances and parameters, such as number of boreholes, how these are coupled (parallel and/or in series), dimension of pipes, and of cause the thermal properties of the boreholes. The upper flow rate limit will be governed by the maximum allowed friction losses in the pipe system, while the lower limit is defined by the heat pump requirements for heating. For direct cooling there is no such lower limit.

ATES systems, figure 2, have quite different technical boundaries. An obvious boundary is that there is an aquifer at site. Not only that, the aquifer must also to available considering other, more public, groundwater interests, environmental issues and regional/local legislations in general. There are also national laws in some countries that may be very restricted on technical usage of groundwater.

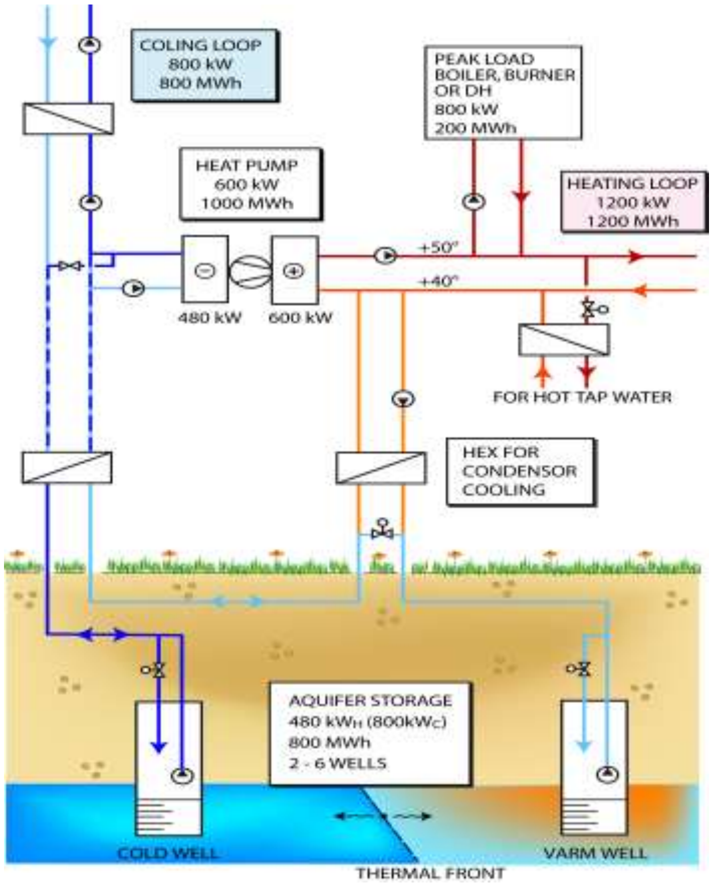


Fig.2. ATES systems have different technical boundaries

In order to protect the rest of the system from problems related to water chemistry, the groundwater loop is normally separated from other fluid loops by heat exchangers. As a matter of fact groundwater chemistry is the dominating cause for operational problems in existing ATES systems. The chemical composition of the water may even be so unfavorable that ATES is not applicable. Therefore water chemistry may be another boundary for technical use, in that case related to corrosion and/or clogging problems.

The aquifer itself must of cause have reasonable size and hydraulic properties, such as permeability and hydraulic boundaries, to be useful for ATES applications. The capacity of aquifer and the wells must of cause correspond to the load requirements of system. From a temperature point of view there may be an upper boundary related to scaling. Temperatures below 35-40°C would normally be okay.

Finally, there must be space enough between the wells to allow a proper thermal function of the storage. The distance between the warm and cold side must be such that a thermal breakthrough does not ruin the function.

4.Geological boundaries related to drilling

Despite of system, the geology at site will play an important role when it comes to drilling of boreholes and wells.

The most common drilling methods for shallow geothermal systems are shown in table 1. As can be seen from the table down the hole hammer percussion drilling (DTH) dominates in consolidated rocks, while conventional rotary drilling with water or mud would be the dominating method for drilling in lose or poorly consolidated formations.

Table 1. Drilling methods for shallow geothermal systems

Type of system	Cable Tool	DTH with air	DTH with water	Conventional Rotary	Auger sys-tems
Closed loop	Never	Dominates in hard rocks	Rarely but in-creased use	Common in sedi-ment rocks	Common for shallow holes
Open loop	Rarely, (large wells only)	Common	Rarely, but in-creased use	Common in sedi-ment rock	Seldom

General issues, related to the surface conditions, which can be looked upon as boundaries are:

- Space for drilling rig and side equipment may not always be at hand.
- Environmental issues like drilling noise above allowed levels, disposal of water and mud, and contamination hazards may limit the drilling proceedings and even lead to a shut down.

Main technical limits or boundaries when drilling with air in consolidated formations are:

- Hitting permeable fractures or cavities with high water yield will makes further drilling impossible unless the flow is sealed off by installing a casing or by grout injection.
- Hitting loose layers, or unstable structural zones, that makes the borehole producing fines continuously. Such zones may not be possible to grout in order to drill further down.
- When drilling with water or mud as flushing medium the main boundary would be highly permeable zones that lead to a total loss of fluid, while the main boundary for auger drilling is hitting larger stones

CHAPTER 5

GEOLOGY

by Iñigo Arrizabalaga

1. INTRODUCTION

The geological framework is a mandatory issue in every shallow geothermal system design procedure. In comparison to conventional heating and cooling installations, the ground is the additional element in a GSHP. While designing a GSHP installation, an accurate knowledge of the geological conditions where the GSHP is located and the way of integrating this data while sizing the heat pump are key parameters in the success of the project.

The differences between rocks and soil, the basic classification of different families of rocks, understanding its disposition in the ground, knowing the fundamentals of ground mechanical, thermal and hydrogeological behaviour are necessary matters in the design of medium and large GSHP systems.

In small systems, a basic geotechnical and hydrogeological knowledge can be useful in order to avoid safety and environmental risks. A great number of designers come from the building side of the geothermal system. Very often, loop design, even of large installations, is provided by the manufacturer of the heat pump several hundred kilometres away from the work site. They do not have a broad enough knowledge of the ground conditions and the site investigation methodology to employ in the project design. This investigation, especially in new drilling sites, will determine the cost and the viability of the geothermal system and the environmental issues.

The most usual problem is to underestimate the importance of geological issues in the design process. At best, it will cause over pricing of the project. In other cases, the system will not run properly.

Common questions are:

- How to choose between an open and a closed loop?
- How can we calculate the length of the closed loop?
- How can we calculate the yield flow from a well to match the building thermal load?
- How does geology determine the drilling method, borehole completion and costs?

A geological approach is necessary from the starting phase of the project. To collect any kind of geological, geotechnical, hydrogeological and thermogeological information for the project area will be useful and can save lots of money.

This chapter aims to refresh, clarify and improve the geological knowledge of GSHP designers coming from the building side of the technology. They will improve the understanding of how the ground works and make communication between members of the interdisciplinary project teams easier.

2. GEOTHERMAL ENERGY CONCEPTS

This chapter will try to clarify some concepts about geothermal energy:

a. Where does it come from?

b. What are the main parameters?

c. Geology

d. What is the relationship between thermal energy and water in the ground?

e. Why a pilot borehole?

a). Geothermal energy is the energy stored in the form of heat below the earth surface.

Low Enthalpy Geothermal Energy or Shallow Geothermal Energy is the energy stored at a very low potential, usually below 25 ºC.

The Ground Source Heat Pump is the most common technology developed to use Shallow or Low Enthalpy Geothermal Energy, usually, but not always, by means of a heat pump.

Low Enthalpy Geothermal energy has several origins. In many sites employed energy may be a mixture of:

- Geothermal deep flow. The Earth core reactor provides, on a human scale, an endless heat flow towards the surface of the planet. As a result, the Geothermal Gradient averages 3 ºC/100 m depth, and a heat flow rate on the surface of the Earth between 30 and 100 mW/m^2

- Solar absorbed radiation. Heat transfer at the surface. Several factors have to be taken into account, such as the fraction of solar radiation diffused into the ground, water percolation and heat transfer with the air by convection and thermal radiation. However, the assumption is often made that the temperature of the ground (for the first 10 m) is a function of the temperature of the surface. Under 10 m, the ground temperature is no longer sensitive to yearly air temperature variation.

- Ground water advection. Ground water flow is able to transfer large amounts of energy along the ground. This process, known as advective flow, is a main agent in many shallow geothermal systems

- Thermal storage capacity of rock. Rock, with its ability to store heat energy, average ≈ 0,65 $kWh/m^3/ºC$, provides a large amount of energy, especially in vertical closed loop systems where a borehole can involve thousands of cubic metres of rock

- Artificial recharge (regeneration). The storage capacity of the rock may provide an excellent low-cost seasonal scale thermal store able to manage waste heat from cooling processes, refrigeration, solar surplus, etc.

b). The main parameters defining thermal properties of the ground are:

- Thermal conductivity of the ground

- Volumetric thermal capacity

- Undisturbed ground temperature.

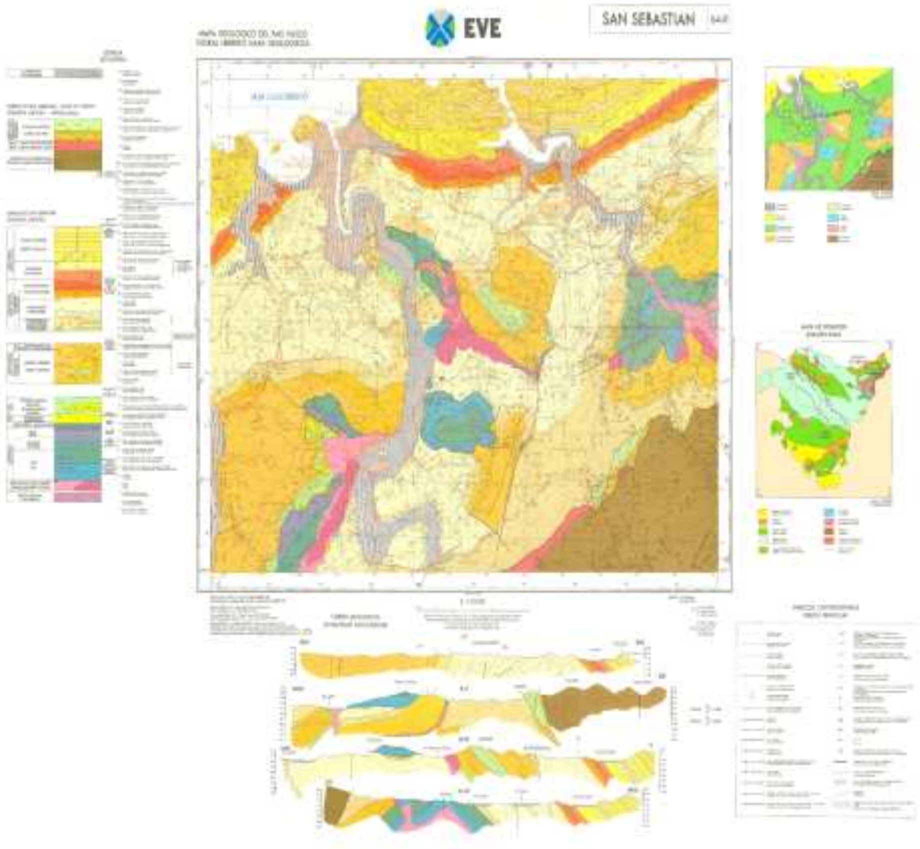
The ability of the ground to transfer and store heat depends on a number of factors, principally:

- *Rock mineralogy*. Generally, the higher the quartz content, the higher the thermal conductivity
- *Density*. High density of the material usually means a closed texture and absence of voids. The higher the density, the higher the thermal conductivity and diffusivity
- *Water content*. Water presence improves the heat transmission even in the absence of flow. It fills the voids, increasing the thermal conductivity of the rock or soil.

c). Geology is also the main agent shaping the landscape. Tectonic forces fold and fault rocks. Weathering, transport and deposition agents are key issues in the tireless transformation of all geological environments. Landscape conditions will determine the project site conditions that fit the drilling equipment.

In addition, geology provides good information about mechanical and geotechnical properties of the rock, which are key influences on the cost of the drilling works (Fig. 1). The main parameters, according to their cost influence are:

Rate of penetration (ROP). ROP will depend on various properties of the rock, mainly:



- Fracture degree

- Texture

- Planes of weakness: exfoliation, stylolites

- Specific gravity and density

- Porosity

- Permeability

- Hardness

- Compressive strength

- Abrasivity

- Elasticity

- Plasticity

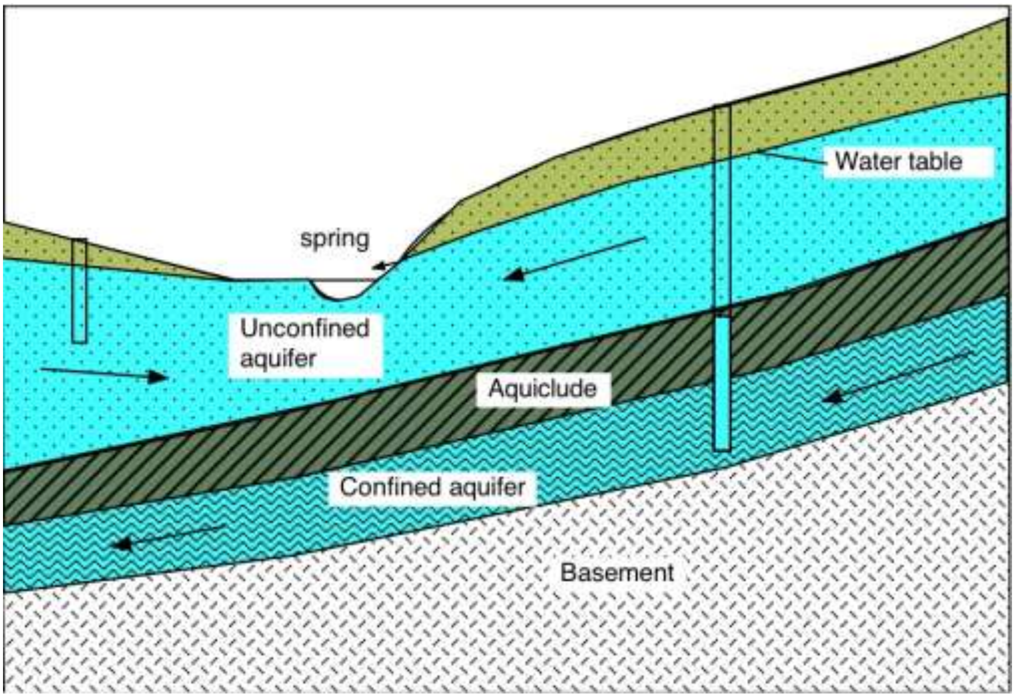
Figure 1. Example of a solid geology map

- Stability:

The ability of the drilled ground to maintain stable borehole walls determines three very important parameters with a very high impact on the project's final cost:

- Diameter of the borehole

- Auxiliary casing needs



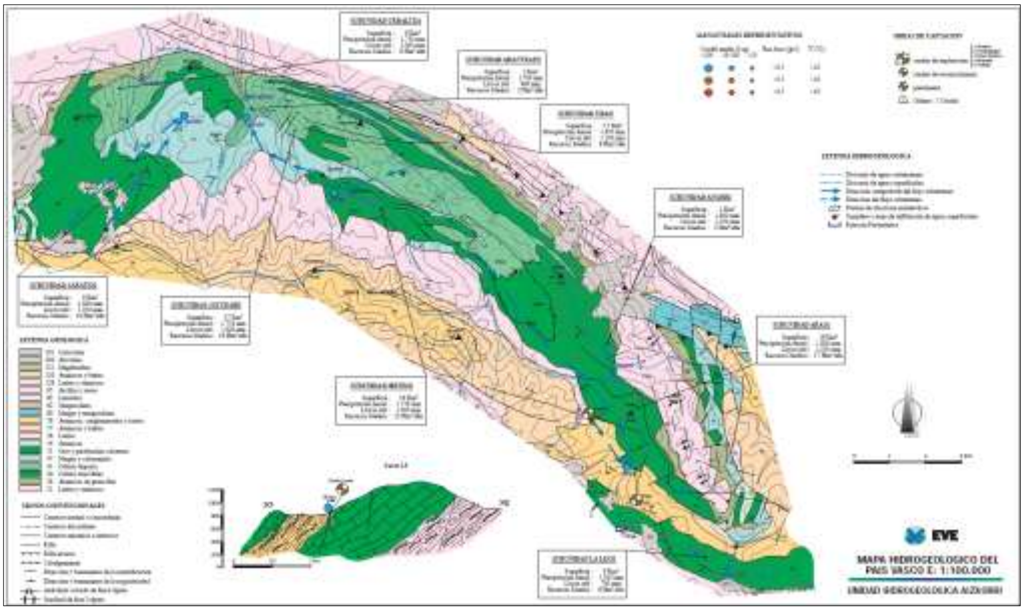


Figure 2. (top) Hydrogeology, aquifer diagram

Figure 3. Hydrogeological map

d). Hydrogeology is another field to take into account for preliminary analyses (Figs 2 and 3).

Ground water presence is of prime importance in GSHP system design procedures, as illustrated by the following five points:

- It determines the typology of the geothermal system. In yielding enough aquifers, the typology of the loop could be directed toward an open loop or Standing Column Well system, sometimes even as a result of an unexpected water yield of the pilot borehole. Otherwise, a closed loop system may be the ultimate solution

- The water table position determines the thermal conductivity of the ground

- Advective flow may transfer a huge amount of energy, increasing the apparent thermal conductivity of the ground and providing higher extraction and rejection ratios
- On the other hand, advection may preclude seasonal thermal storage in the ground
- Ground water pollution is the main environmental risk of GSHP technology. An adequate knowledge of the hydrogeology of the geothermal site is compulsory to evaluate pollution risk and to design the sealing sketch for the borehole when necessary.

e). The pilot borehole

A good example of a geological investigation tool for vertical closed loop shallow geothermal systems is the pilot borehole. Drilling a pilot borehole with an adequate geological control provides full value information about:

- Lithology log
- Ground fracture degree
- Hydrogeology
  - Water table position
  - Aquifers
  - Productivity, specific flow rate, drawdown
  - Hydrochemistry
  - Filling/grouting selection
- Drilling parameters
  - Formation stability, voids and holes
  - Drill ability
  - Diameters
  - Auxiliary casing need
  - Drilling speed
- Drilling Cost
- A borehole for installation of a PE exchanger for Thermal Response Test (TRT)
- An additional pipe for borehole logging, undisturbed ground temperature, temperature log before, during and after TRT, other kinds of geophysical logs, etc.

3. TECHNICAL AND PROFESSIONAL RESOURCES

The technical resources needed for this phase will differ according to the scale of the project.

In small size installations, below 30 kW, basic geological knowledge, training and experience may be enough. Many countries and several autonomous regions have geological services using comprehensive documentation about the work site, geological and hydrogeological maps, groundwater databases, groundwater pollution risk, soil and slope maps, etc.

In addition, many drilling companies may provide information about lithology, the geological column, groundwater prognosis, etc. This helps us to supply the geological information requested for mining, water and local authorities

Larger size installations, over 30 kW, require deeper and more specific geological knowledge. Integrating a hydrogeologist into the project team could be compulsory, especially in groundwater-based open loop systems.

The profiles of professionals working in the geothermal, as in the hydrogeological, field vary.

The professional background of people working in this field should be a ground-based qualification: geology, mining or civil engineering, with a good knowledge of hydrogeology. The Designer must be able to understand a geological map. He must know, at least, basic rock classification and be able to identify the main rock types in his work area. He should also have some basis in structural geology and an understanding of geological relations between different ground materials, their orientation and deformation processes.

In many medium and large scale projects, it may be compulsory to have a relevant geothermal qualification in order to get appropriate risk insurance or to integrate the geothermal item into the building project.

3.1. Using the resources

Geological knowledge must be integrated into GSHP from the first stage and will be present throughout the design process. Geology determines directly or indirectly:

- Loop typology: Open, Closed, Standing Column Well
- Thermal properties of ground/groundwater
- Loop viability: digging/drilling system, well/borehole completion
- Environmental issues.

The scope is very complex according to the chosen typology. It could vary from geological/geotechnical cartography to a pumping test of a groundwater abstraction or re-injection well.

4. ENERGY EFFICIENCY AND ECONOMIC COST BENEFIT

The energy efficiency of a geothermal system is fully related to the typology of the circuit. Efficiency in a geothermal system ranges from a Seasonal Performance Factor (SPF) of <3 in many horizontal dug closed loop geothermal systems up to >5 in several groundwater source open loop systems. For the same typology, e.g. vertical closed loop system, building thermal load and exchange length performances could range from <3.5 to >4.5 depending on ground thermal conductivity and groundwater Darcy velocity.

Ground properties, building thermal loads and energy cost will determinate the viability of the geothermal alternative. Loop typology will define the cost range of the geothermal system. Vertical closed loop systems can usually supply a few hundred thermal kW. It may easily cost >1200 € per installed power kW, with a payback time over 12 years.

In contrast, an open loop ground water system can provide several MW of thermal power and its cost may be cheaper than 100 €/kW with a payback period of a few months.

4.1. Regulations

The main specific regulation regarding this domain is about filling and grouting materials and procedures. Several central Europe countries, such as France, Germany, Austria and Switzerland require the borehole to be grouted with a sealing compound, usually cement and bentonite mixtures, in order to avoid aquifer pollution. But usually, after grout placement and casing removal, no further tests are carried out to verify the grouting position. These regulations can be useful in some geological conditions, e.g. in karstic terrains, low water table positions, gypsum terrains, boulder unconsolidated terrains, but not in others.

In other countries, such as the Scandinavian area, the borehole is filled with water. The wellhead casing annulus is grouted and the inner space between U-pipe and casing is sealed with expansive rubber packing. This completion is considered safe enough to ensure that no pollution of aquifers occurs from the surface through the borehole.

Many countries are unregulated. As in many things, the sealing procedure must be conditioned by geology and hydrogeology. Often, prevention of cross pollution between different potential aquifers is not possible with grouting alone. This needs specific treatment, for example, the placement of a grouted casing isolating the upper aquifer before the lower aquifer is drilled. A very similar situation may take place in case of strong artesian conditions. On the other hand, a requirement to seal a low permeability formation without aquifers along the entire borehole is unnecessary and only increases the bore field cost and decreases the thermal transmission through the borehole annulus.

The same prescription is not always the best one for different illnesses. Qualified staff must study and design the safe solutions for each hydrogeological situation.

5. CONCLUSIONS

Geology defines the ground behaviour of thermal energy. A fitted design of a medium or large size shallow geothermal system cannot be done without an analysis of geological issues.

Designers need to understand heat transfer basic concepts in the ground, the different factors affecting the energy budget, heat recharge and discharge and the role of ground water. They must also know some basic geology and hydrogeology, the main rock formations and lithologies, the position of the aquifers and the vulnerability, at least of the specific work area, in order to choose the best circuit typology in each place. They must be aware of consequences and risks of a bad geological evaluation.

The most common consequence of misuse is increased cost and the misfunction of the designated geothermal system. In the case of inappropriate circuit typology selection, a more expensive alternative may be chosen, increasing the cost of the geothermal system. Sometimes, the economical limit may be exceeded and the geothermal alternative will be rejected. A poor knowledge of the thermal properties of the ground can also lead to the wrong decisions. An even worst option can be in the case of underdesign. The system will never work properly or troubles will appear after a few years of operation. Moreover, an incorrect geological evaluation can produce geotechnical and environmental hazards, some even with penal consequences.

5.1. The future

Future evolution of this matter will involve a stronger influence of professionals with ground-related backgrounds in geothermal design. In medium- and large-scale projects, their

knowledge will be compulsory inside a multidisciplinary work team. Determining ground properties, ground water behaviour, thermal storage ability of the project site or choosing the best and safest environmental heat transfer completion sketch of the borehole will be a specialist task. Hydrogeological and geophysical tools will be widely employed and adapted to improve bore field design and work quality control.

5.2 FURTHER INFORMATION

Bibliography

Many geothermal design handbooks dedicate at least a chapter to explain some basic geological concepts.

Websites

European Union countries have a wide net of geological surveys, many with web services offering useful information, geological and hydrogeological information, water spot data bases, ground thermal conductivity inventory, groundwater temperatures, hydrochemistry, etc.

See: http://www.uni-mainz.de/FB/Geo/Geologie/GeoSurv.html

Other associations of interest are:

International Association of Hydrogeologists (IAH): www.iah.org

National geologist, mining and civil work engineering associations have plenty of information on their websites about these topics.

See: http://geology.about.com/ where you will find a lot of geological information to retrofit your secondary school geological lessons.

Chapter 6

SHALLOW GEOTHERMAL DRILLING METHODS

By Olof Andersson

1. Introduction

Shallow geothermal systems are commonly drilled to a depth of less than 200 m and consist of boreholes for closed loop systems or wells for open loop systems.

It is assumed that any driller working in the field of Shallow Geothermal has a certain skill in drilling either by experience and/or by education. However, at present, anybody could claim to be a driller since there is no real education with approved certificates for drillers in any of the EU member countries.

Depending on the geological conditions and country specific drilling culture, the equipment's and methods for drilling and drilling procedures vary substantially from country to country (sometimes also within one and the same country).

- **Drilling boreholes and wells is an art that relates to carefulness, sensibility, imagination and experiences gained under many years**
- **The occupation requires a broad knowledge about machinery, side equipment's, geology, hydrogeology, safety, "hot works", enterprise and legislations**

About the occupation being a driller the following characteristics should be kept in mind.

In this chapter an overview of optional drilling systems is given as a basis for know how transfer of proper methods and procedures between countries and regions.

2. Why should drillers and installers care about different drilling methods

The utilization of the underground as a thermal energy resource is still at an early stage in most EU countries. In the few countries with a longer tradition, such as Sweden and Germany, the drilling methods have been adopted for shallow geothermal and hence the experiences from these countries could make it easier for new countries to develop their drilling methods. This will of cause be in favour for a faster growth of applications and may also in a longer perspective be the basis for a common EU certification process.

3.Classification of drilling methods

Drilling is a process where certain tools are used to create a slim hole in the ground, often to a considerable depth. The drilling equipment is fed by energy, often obtained by diesel or electrical driven motors and hydraulic loops. The efficiency of the process vary greatly and depends on how much of input energy is actually used to create the hole and how much is energy losses in the process. The energy is not only used for the drill bit to penetrate the soil or rock, but also for creating the forces needed on the drill bit (thrust) and the resistance against rotation (torgue). Furthermore, some is also used for flushing the cuttings to the surface. By regarding the process of destruction, the cleaning of the borehole and the forces applied on the drilling equipment, the most common drilling methods can be described as shown in figure 1.

	Cable tool drilling	Hammer drilling with air	Conv. Rotary Drilling	Auger drilling	Sonic drilling
Applied mechanical forces	Gravity	(Thrust) (Torgue) Percussion	Thrust Torgue	(Thrust) Torgue	(Thrust) (Torgue) Vibration
Hole cleaning method	Lifted with bailer	Flushed with air or water	Flushed with water or mud	Lifted or screw transport	Core barrel Air or water Push aside
Destruction forces	Crushing by blows	Crushing by high frequency strokes	Crushing by pressure (Jetting)	Shearing	Push aside Crushing (Jetting)

Figure1. Description of common drilling methods based on applied forces and processes

4. Method descriptions and evaluation

4.1 Cable tool drilling

The cable tool drilling originates from China where it was used for more than 2 600 years ago. It became a common method in Europe when drilled wells became common for water supply and it stayed as the dominating well drilling method up till the 1950:ties: It was then gradually replaced with the more efficient and much faster rotary drilling methods.

In shallow geothermal drilling it is still occasionally used for large dimension screened wells in course formations such as river beds and eskers.

4.2 Hammer drilling with air

Hammer drilling using pneumatic top hammers was introduced in the early last centaury. It was at that time used for construction drilling and blast-hole drilling in the mining industry. In the 1970: ties a Down-The Hole (DTH) hammer was introduced for water well drilling in hard rocks. From then it has been further developed to be one of the most efficient drilling methods and is commonly used for drilling boreholes in crystalline rocks, as well as in consolidated sedimentary rocks. The method is dominating in Baltic-Scandinavian shield area with granites and gneisses and Palaeozoic sedimentary rocks at the shield border. However, the method is also spottily used in the rest of Europe, especially in regions with consolidated rocks. A typical drill site with a normal size rig and compressor is shown in figure 2.

Figure 2. A drill site with hammer drilling showing the rig and containers for cuttings and a compressor placed away from the rig.

The DTH hammer is by tradition driven by compressed air that is obtained from powerful compressors. In the 70: ties the size of compressors had about 10 bars working pressure, to be around 20 bars in the 90: ties. Currently, it is common to use compressors with 30 bars, which makes the penetration rate to be as fast as 0.5-1.0 m/min drilling in granites and gneisses.

The rigs designed for hammer drilling are normally capable of handling drill rods to a depth of 200-250 m that would be a practical depth limit for drilling closed loop systems. However, this limit could be restricted by unfavourable geological structures such as hitting tectonic unstable fractures zones. More often the target depth is restricted by entering high permeable fractures. In such cases the air force is used to carry the water up to the surface leaving less power for driving the hammer. Even with a 30 bars compressor further drilling is not possible at a water production of 15-20 l/s.

Drilling in sedimentary rocks will not be possible, unless the whole formation is consolidated. For example, a loose layer of unconsolidated silt or sand in a consolidated formation will continuously produce material due to the hydrostatic pressure towards the borehole. This will in worst case put an end to further drilling and will of cause be the depth limit for inserting a borehole heat exchanger.

An advantage with hammer drilling is that the holes can be drilled directional. This means that several holes can be made from almost the same spot forming a triangle shaped configuration. Angles up to 45^{o} are sometimes used, but more common is to direct the boreholes with an angle of 10-20^{o}. This has become common for shallow geothermal applications in cities with a limited surface for drilling.

Hammer drilled boreholes will in any case never be perfectly straight. Measurements made in “straight” boreholes show a deviation at 150 m that typically is in the order of 10-20 m. This is of cause a hazard, especially if a system consists of densely placed boreholes (BTES). Under such a situation one or several boreholes may cross each other causing damages. This problem could at least partly be avoided by having steering guides on the bit, hammer and drill string.

Another danger with closely placed boreholes is that fractures may connect the boreholes. In such cases the high air pressure used at drilling may cause damages to already complete nearby boreholes. This type of problem would be typical for not grouted boreholes in Scandinavia, but would not be a major problem for grouted boreholes. The main observations using DTH drilling for shallow geothermal in Scandinavia are listed below.

- **Rocks with fractured zones may cause stability problems and create an obstacle for placing the collectors**
- **Hitting permeable fractures in the rock will slow down the rate of penetration and in worst case make further drilling impossible**
- **Getting rid of produced ground water and cuttings may cause extra problems and costs**
- **Systems of fractures may create pressure break through between closely located boreholes (BTES especially) and cause different types of damages**
- **In BTES applications with deep boreholes, special measures may be taken to avoid cross-hole penetration**

4.3 Hammer drilling with water

In later years a hydraulic water driven DTH hammer has been developed and introduced on the shallow geothermal drilling market (Wassara), preferably in Scandinavia. Some facts about this method is given below and an illustration of the method in figure 3.

- **Developed by LKAB in the 1990:is**
- **Mostly for blast hole drilling in the mining industry**
- **Works with high pressure 150-200 bar**
- **Clean water has to be used at a flow rate of 3-5 l/s**
- **Cleaning and recirculation of the water is still under development**
- **Drilling Rate often higher than DTH with air**
- **Drilling Cost, slightly higher than DTH with air**
- **Mostly used for deep boreholes (> 200 m) and deep casing drilling**

Figure 3. The Wassara system has water driven hammer using clean water to function properly.

Since the Wassara method combines the efficiency of percussion drilling with the benefits of having a hydraulic stabilising overpressure in the borehole such as in the conventional rotary method, the method has gradually been more and more used for shallow geothermal in Scandinavia. Especially this is the case for deeper holes in crystalline rocks and in regions with younger sedimentary rocks.

A limiting factor with Wassara is that the flushing water has to be clean from particles, especially the lower fractions of silt and upper of clay. A system for cleaning the return water from cuttings is still to be developed to make the system fully compatible on the market. Hence, the consumption of water while drilling is therefore still a substantial obstacle.

4.4 Conventional rotary drilling

Governed by geological conditions, conventional rotary is the dominating drilling method in areas with sedimentary rocks. It was originally developed in oil and natural gas industry in late 1800-early 1900 and became the “oil drilling method”, and still is. The method was scaled down to shallow water drilling in 1940: ties and has since then gradually replaced the cable tool method worldwide.

In consolidated sedimentary rocks a three cone “roller bit” is used to crush or break the rock into pieces (cuttings). For drilling in soft rocks another type of drill bitt is used, a drag bit. This will carve pieces of the rock at the borehole bottom. By flushing a fluid through the drill rods and out through the drill bit the borehole bottom is cleaned from cuttings and transported to the surface in the annular between the rods and the borehole wall. The fluid is then cleaned by separating the cuttings from the fluid using a sieve (shale shaker) and by sedimentation in tanks or a sedimentation pit. The fluid is then and recirculated back through the rods (straight circulation). For larger dimensions the fluid is circulated the other way around (reversed circulation). For shallow geothermal closed loop systems the straight circulation method is practically always used and if possible water as the fluid medium.

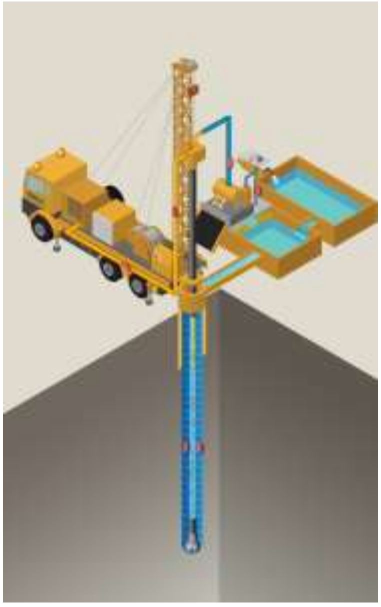


Figure 4. Conventional rotary drilling and different bits used (a three cone roller bit and a drag bit).

Depending on geological and hydrogeological conditions, additives have to add to the water. This is commonly done in order to stabilise the borehole (prevent borehole collapse) and/ or to prevent loss of fluid if high permeable layers are entered. A common such additive is to mix the water with bentonite, a natural clay mineral. Drilling wells for open loop systems, bentonite should be avoided and replaced with a substance that is self breakable, such as organic polymers (CMC). A fluid with additives that changes its properties is called a drilling mud.

The rotary method has several advantages compared to hammer drilling with air. The most pronounced one is that the borehole can be kept stable by the hydrostatic overpressure that is created in the borehole compared to the hydrostatic pressure in the formation. This is of cause not the case if an artesian aquifer is reached. However, in such a case the fluid can be made heavier by adding for example fine grained chalk or something else that increases the density of the mud. On the other hand an obvious disadvantage is that the conventional rotary in hard rocks will be comparatively slow, and in practice not even suitable for magmatic rock types.

Common problems and observations drilling with conventional rotary in sedimentary rocks are stated below.

- **Rocks with fractured zones may cause stability problems and create an obstacle for placing the borehole heat exchanger.**
- **High permeable formations will cause loss of circulation that will slow down the performance.**
- **Hitting artesian aquifers may cause the borehole to collapse and in worst case ending with a stuck pipe.**
- **Most of these problems can be solved using a proper mud technology, normally based on bentonite.**
- **However, bentonite mud should not be used for open loop wells. Us instead a polymer mud (CMC)**

4.5 Auger drilling

The auger drilling method is based on a well known way of making holes into a soft material by a carving principle. It is commonly used for geotechnical site investigations, but is in a larger scale also used for water well drilling and shallow geothermal applications to a moderate depth.

In principal a screw is rotated down the soil and either drawn back at certain intervals for empty the flanges, or (more commonly) the material is automatically transported by the flanges to the surface as shown in figure 5.

Figure 5. Auger drilling that in this case is done with hollow stem equipment.

For shallow geothermal applications the method may be used for moderate depths and systems placed closed loop systems penetrating fine grained sediments. For drilling in rocks, other methods should be considered.

4.6 Sonic drilling

The sonic drilling method is fairly new on market, even if it was developed during the 1990: ties. The driving force for penetration is a high frequency vibration that is transferred from the rotary head down to a drill bit. As such it reminds of the top hammer method, but with the distinction that the energy losses are much lower.

The method was originally developed for core sampling in unconsolidated formation, but has then been further developed also to drill open holes in almost any type of rocks. For making that possible it also contains a flushing possibility, ether by air or a fluid. This makes the method very flexible when it comes to drill in different geological situations. However, there are no experiences stated in literature yet to value the method for shallow geothermal applications.

Except for the flexibility when it comes to handling different geological conditions there are a couple of potential advantages with the method. These are less maintenance, less noise and easier draw back of casing, all compared to hammer drilling methods.

5. Overburden drilling

5.1 Temporary casing

In the majority of situations shallow geothermal drilling involves drilling through the overburden and at this stage place a casing before continuing with an open hole in solid rock. In rare cases the soil is firm enough to be stable close to surface. If so, a casing could be replaced by a standpipe that is drilled or pushed down just a meter or so into the ground.

There are two kinds of casings that are related to the drilling procedures and the site specific geological conditions. One is the temporary that is thread connected and typically rotated down at the same time the hole is being drilled just below the casing. This is the standard method for grouted boreholes and is preferably performed with a rig suitable handling rotation of both the casing and a drill string at the same time. Typically, a pilot bit is fixed to drill string and a ring bit at the end of casing. During drilling the cuttings are flushed to surface by air, or more seldom with water.

If drilling is made by conventional rotary, the casing can be set after a hole is being drilled and stabilised. The casing is then hung down to bottom of that hole and the open hole can then be drilled in smaller dimension.

After grouting, the casing is withdrawn and disconnected. During this stage the grout may be entering permeable zones that were cut of by the casing during the grouting procedure. This may call for a second grouting up to surface at a later stage when the first grout has hardened.

5.2 Permanent casing

In Scandinavia permanent casing is used. According to the norms, the casing should be drilled down to at least two meters into a firm and water tight rock. The casing is drilled with special equipment called Overburden Drilling with EXcentic bit (ODEX), se figure 6.

Due to the forces involved using the ODEX method, the casing has to have welded joints. Furthermore and following the norms, the casing has to be sealed at the lower end in a way that water from surface can not enter into the bore-hole. This is of cause for protection of the groundwater in the rock that else could be contaminated by a flow in annular between the casing and borehole wall, a space that is approx. 5 mm wide. This space is normally grouted, but seldom the whole way up to surface. The common procedure is simply to fill the bottom of the hole with 3 m of grout, then lift the casing 3 m and let it fall back again. Finally the drilling shoe is pushed hard against the bottom to seal of the grouted space. After that the drilling of the full hole starts more or less directly.

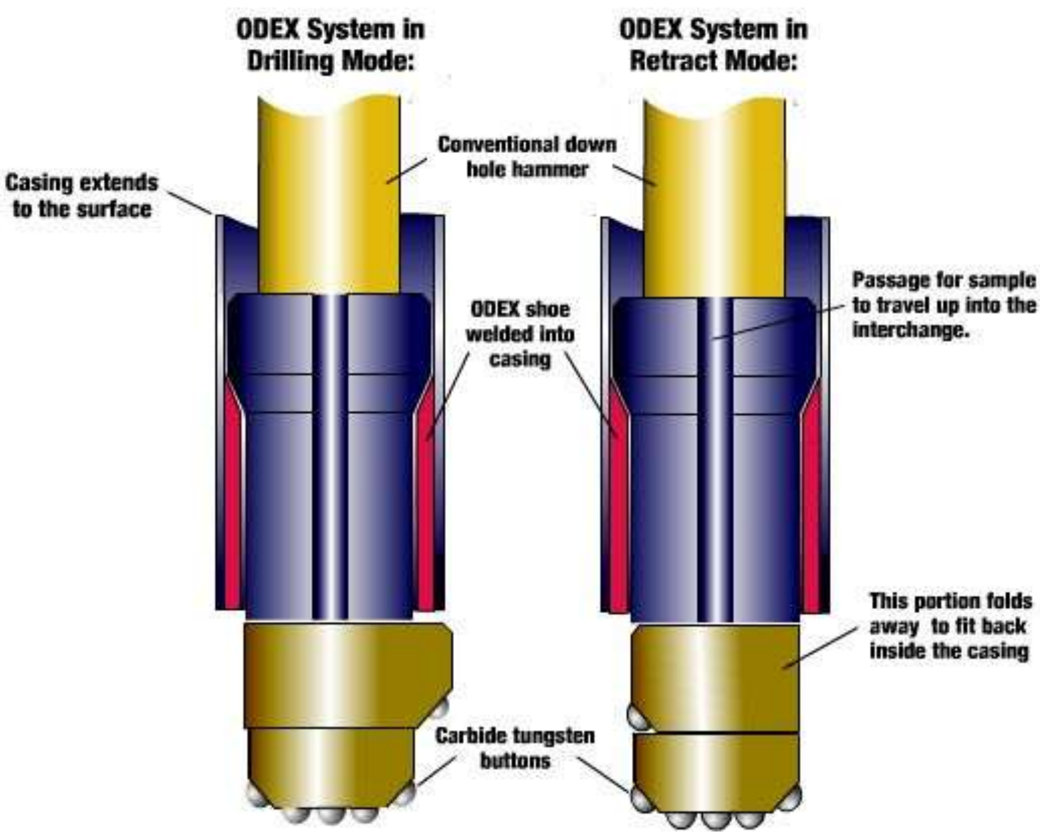


Figure 6. Principal and equipment for the ODEX drilling method

The ODEX method that was introduced during the 1970: ties, has spread worldwide and been followed by a number of other equal methods, such as TUBEX, NO-EX, and SYMMETRIX, the two latter ones being ring bit methods. However, they have all in common that the casing is driven down without rotation of the casing, only the ring bit is rotated.

Read more

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Chapter 7

Test drillings and measurements while drilling

By Olof Andersson.

1. Introduction

A large shallow geothermal system contains a number of boreholes for closed loop systems or wells for open systems. Before the actual construction it is of cause important to recognise the specific features and properties of the underground at the site in order to avoid costly failures and problems. Test drillings is therefore an essential part in any large scale shallow geothermal system.

2. Why should drillers and care about test drilling

A drilling or installation company must be aware of why test drillings are vital for successful installations. As illustrated in figure 1 a proper test drillings will generate information's of the underground properties, which are essential for the design of the system. Test holes will also be the input for reorganizing the drilling ability and potential drilling problems, thus making it possible to make drilling cost estimate.

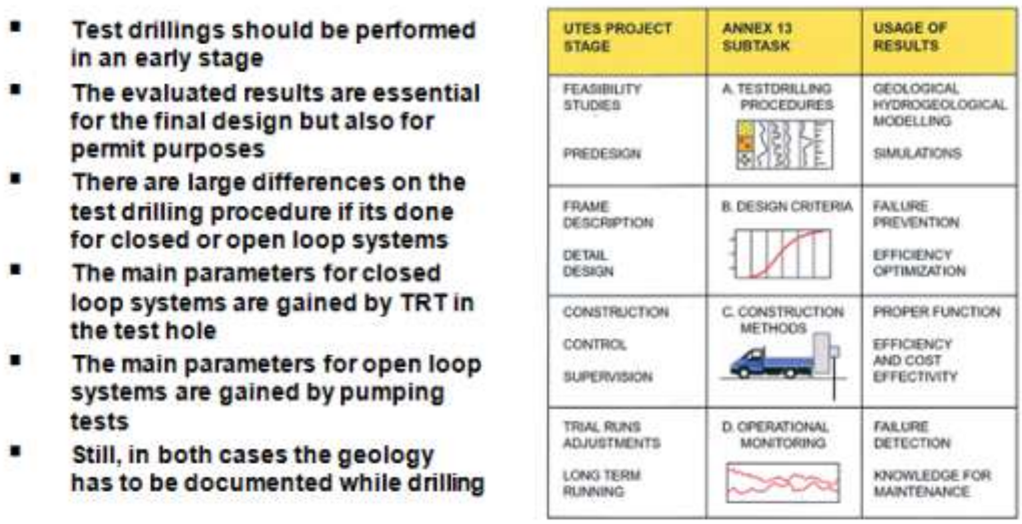


Fig.1. A large scale shallow geothermal system should contain test drillings as basis for design

3. Potential measurements during and after drilling

During drilling the test hole a number of parameters can be obtained by sampling and measurements in order to have a proper description of the geological layers that are penetrated. This recording will often be on the drilling contractor to collect and deliver to the designer. The potential information that can be gained during drilling (MWD) is principally shown in figure 2.

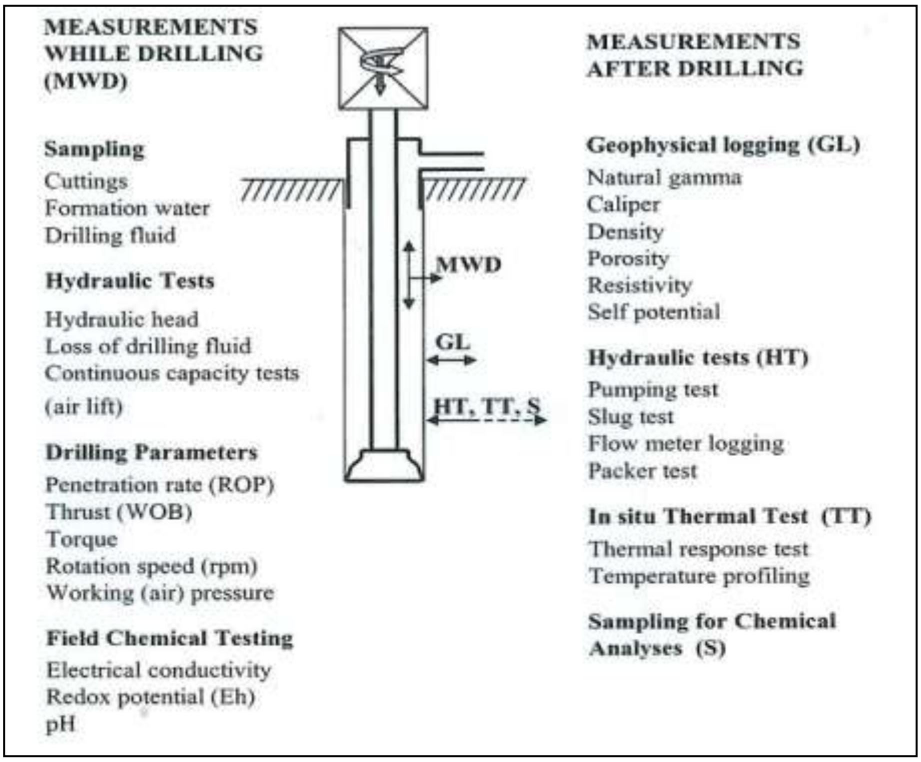


Fig 2. Potential parameters that can be achieved from a test drilling during and after drilling

Parameters that is possible to document while drilling depends on what drilling method being used. Still, sampling of cuttings would always be an item as well as measurements of at least some of the drilling parameters.

After drilling and completion a number of different tests can be made, sometimes performed by the driller, but in other cases as a third part service. For closed loop systems it is recommend to always performing a thermal response test (TRT) in order to estimate the thermal properties of the geological strata. For open loop systems different forms of pumping tests are carried out combined with chemical analyses of the groundwater.

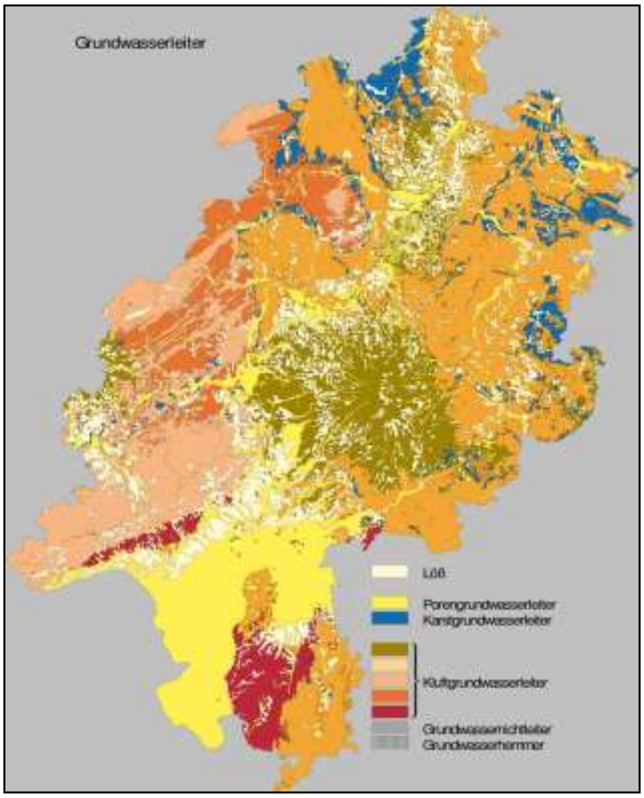
4.Planning a test drilling

Depending on if the system is for closed or open loop applications, the test drilling program would be quite a lot different when it comes to the content, However, a general approach for planning test wells or test drilling for boreholes would be to follow a certain procedure in order to cover most of the items that are important to find out in order to design a system.

Already at an early start it may be of importance, even for a driller, to have a broad conceptual knowledge of the project in order to understand why test holes are being made and to what extent. This will make it possible for him to discuss the test drilling program with the designer in early stage and to have second opinions on the work he is asked to perform. A checklist for such a procedure is shown below by cooperation with the designer.

- **Find out the order of heating and cooling loads for decision on size, number and location and distance between test wells or boreholes**
- **Verify the surface ground conditions in order to place the boreholes or wells on proper spots**
- **Find out the geological and hydro- geological conditions in the area in order to plan the drilling.**
- **Based on the information from the above points, work out a conceptual drilling and documentation program**
- **Finally, make sure that the local regulations and possible restrictions are covered, and if required, that drilling permits are in order**

For investigate the geological conditions at site it is a good idea to consult geological maps that are available in most countries. The way of finding information is illustrated in figure 3.



- **Topographic, geological and hydrogeological maps**
- **Existing hydrogeological investigations, geophysics included**
- **Survey of wells in the area (archives or data basis)**
- **Investigation of property boundaries and land use**
- **Checks on constrains or obstacles to use ground water in the area**

Figure 3. Consulting geological maps and other existing documents is a to get information way for planning test drillings

When it comes to planning the documentation program, the following parameters would be sufficient for most applications.

- **Stratigraphical units by samples of cuttings (all projects)**
- **Grain size distribution in the aquifer by dense and careful sampling and sieve analyzes of cuttings (mainly open loop projects)**
- **Special sampling drilling methods may be required for well screen design, i.e. coring, (only open loop projects)**
- **Rate of penetration, preferably as a function of other drilling parameters (all projects)**
- **Air lift capacity as a function of depth (all projects)**
- **Loss of fluid, levels and amounts (all projects)**
- **Static head after drilling (all projects)**
- **Water chemistry (mainly open loop projects)**

5. Methods for geo documentation

Depending on the drilling method used in the test drilling the documentation possibilities will vary and the samples and measurements will also be of different qualities. In this sense, sampling using hammer drilling with air would be much easier and have a higher quality since the cuttings is immediately brought to the surface at a very high speed. Sampling at conventional rotary drilling and straight flushing with water or mud will have a much longer transport time and the cuttings from different levels will be mixed unless special sampling methods are being used.

One simple way of having better sampling quality at conventional rotary drilling is to separate the transport of cuttings by interrupting the penetration and only flush for a period of time. The cuttings will then represent the interval been drilled before the interruption. At a depth of 100 m the transport time for cuttings is about 2 minutes. By have an interruption time of approx. 30 seconds will secure the sample.

Drilling with air and entering water holding fractures or permeable porosity layers will result in water entering the borehole and be lifted out of the hole together with cuttings and air. The deeper the inlet of water is placed, the higher the flow rate. This situation can quite easily be used to document the so called “air lift capacity” as function of depth. The way of measuring is done by letting air, cuttings and water enter a container and to keep a constant water level in this. Before adding a new drill rod the drill string is pulled a meter above the hole bottom and the compressor will pump out any water entering the borehole. The volume of water entering the container is simply measured for a minute or so and plotted in a diagram. This diagram will not tell where the permeability is but also the order capacity and is therefore very informative for further design and planning of drilling and drilling depth.

The same type of measurement can be made when drilling with conventional rotary. In this case the lost circulation is measured in the return container used for sedimentation of cuttings. However, the volume of make up water and mud pump stokes must also be known to have a good measurement.

The rate of penetration (ROP) is a function of forces used in the drilling process, see the table below. If WOB (rotary drilling) or Air working pressure (at hammer drilling) is kept constant the ROP will tell about the degree of consolidation of the layers being penetrated. This information can then be used to detect units with different mechanical properties and are therefore of great value.

Drilling Parameters
• Rate of penetration (ROP)
• Rotation speed (RPM)
• Weight on drill bit (WOB)
• Rotation resistance (Torque)
• Fluid flow rate (SPM)
• Air working pressure (Bar)

Table1. Drilling parameters that can be used for geological evaluation and proper drilling procedure

Most process parameters can quite easily be logged with pressure devices on the hydraulic systems, the torgue included. The torgue is closely related to WOB in rotary drilling, but will be less important in hammer drilling where the air pressure is the dominating parameter for ROP.

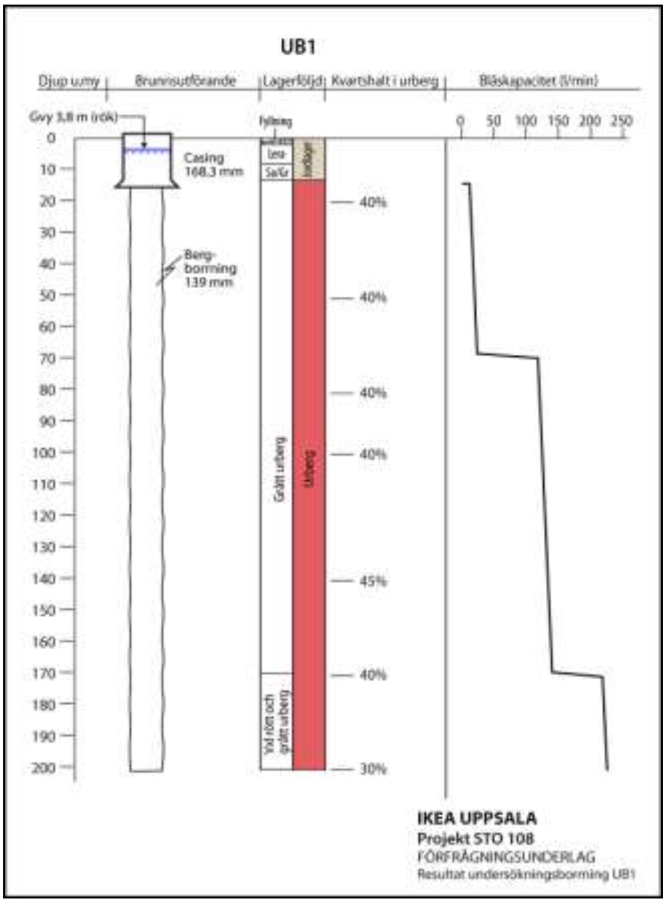
6.0 Examples of test drillings

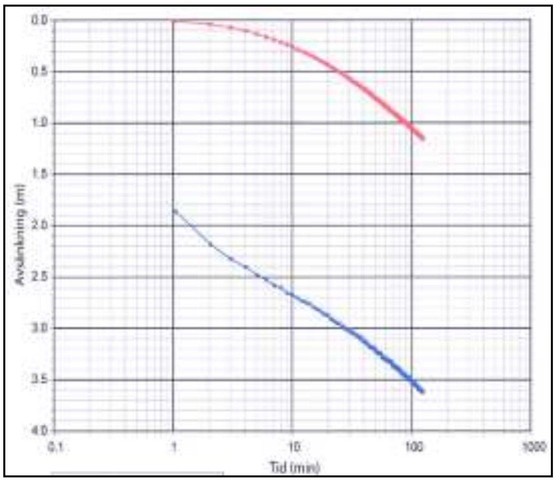
6.1 In crystalline rock

In figure 4 an example of results from a test drilling for IKEA Uppsala, Sweden is given. It is one out of two test holes made for BTES system covering a borehole filed of approx. 2 500 m^2. The number of boreholes is 100 that are drilled to depth of 170 m. The space between the boreholes is approx. 5 m.

As can be seen on the figure the dominating rock is granite overlaid by some 15 m of overburden that consists of gravel and sand with clay on top.

The test holes were drilled with air flushed DTH, and during drilling samples were taken and the airlift yield was measured each 6 meter. After drilling and before inserting the BHE, both holes were capacity tested in order to find out the permeability of rock fractures and the hydraulic connection between the two boreholes.





Capacity test
- Duration: 120 minutes
Flow rate: 2 l/s
- Draw down: 3.65 m
- Delta s : 0.8 m
K-value : 0,2 mm/day
- Connection to UB2 established

Fig 4. Results from a test drilling for a BTES plant in crystalline rock to IKEA Uppsala, Sweden

A couple of weeks after completion of the boreholes both of them were TRT tested as basis for the design of the borehole storage.

Based on the results from the test holes the driller calculated to drill the boreholes down to the lower fracture zone and could fairly well estimate the cost of drilling in his bid.

6.2 In sedimentary rock

The other example is from a test drilling in a limestone containing at least one permeable zone that is related to porosity as well as some fracture systems.

The location is Malmö in south west Sweden, a city with a number of existing ATES plants in the same limestone. Also this test holes was drilled for an IKEA store in order to find the best locations for an ATES system. Two wells were drilled by DTH drilling with air. The results from one of these test wells is shown in figure 5.

wells. Since the limestone is consolidated, the drilling was made by air flushed DTH. The result is shown in figure 5.

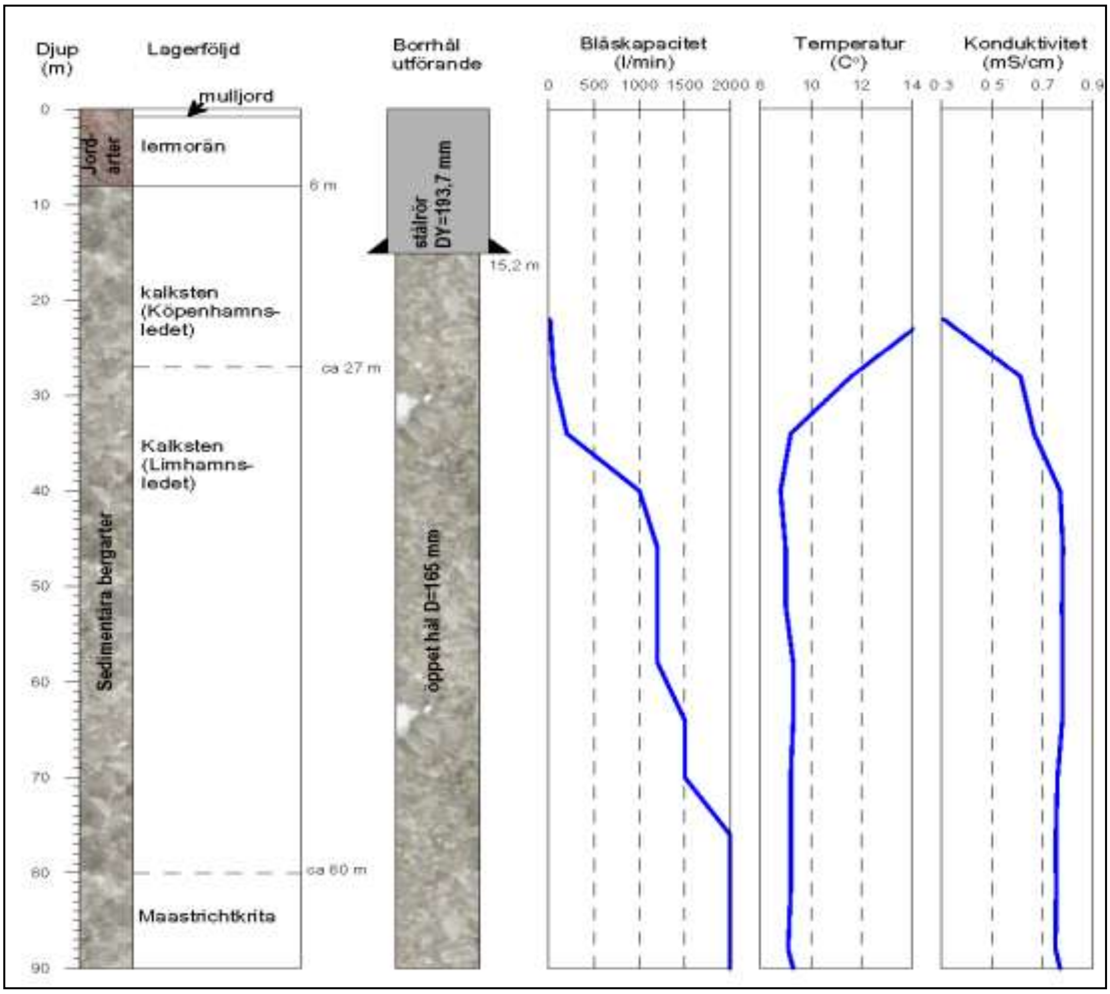


Fig 5. Results from a test drilling for an ATES plant in limestone to IKEA Malmö, Sweden

From the temperature and water conductivity curves it was indicated that the aquifer had the same water quality. The impermeable upper limestone at top overlaid by a clayey till, and a static head close to the surface point at an aquifer that is confined.

The airlift capacity curve clearly shows that the top of the aquifer is located to a depth of approx. 35 m and that it ends about 75 m. By these measurements it can be stated that the aquifer is roughly 40 m thick and that the permeability is related to a combination of prime porosity and a few fracture systems.

After well completions and capacity tests with water sampling and temperature measurements, the site investigation proceeded with a longer pumping test. Finally, a system was designed based on these results and an ATES plant was constructed with five warm and six cold wells.

Further information

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Chapter 8

Thermal Response Test (TRT): practical recommendations for drillers

By Marc Sauer and Burkhard Sanner

1. Reason and principle for TRT

The Thermal Response Test (TRT) is a tool to investigate ground thermal parameters. While the theory and the use of the basic principles date back to the 1970s, the first mobile application of TRT is reported in Eklöf & Gehlin (1996). Sanner et al. (2005) give a full account of the development and of the world-wide status of application, as well as on first guidelines on how to perform a TRT.

With the TRT the following parameters of the ground are determined

- Thermal conductivity [l] describes the ability of the soil/rock to conduct heat. A higher thermal conductivity always increases the efficiency of the BHE. The same amount of heat is transported with a smaller temperature difference when conductivity is higher. *This parameter is site-specific and cannot be influenced by engineering.*

- Thermal borehole resistance [R_b] describes the loss of temperature from the ground to the heat carrier fluid. A lower thermal borehole resistance always increases the efficiency of the BHE. It is dependent upon:

  - borehole diameter
  - pipe size and configuration
  - pipe material
  - grouting
  - heat carrier fluid
  - laminar/turbulent flow

  and can be adjusted by the designer

- Undisturbed ground temperature [T_0] is given as the average temperature over the depth of the BHE. A high T_0 always increases the efficiency in heating mode (while it decreases the cooling efficiency).

- NOT in any way a parameter that is known as „specific heat extraction“.

The interpretation of the recorded data also allows conclusions on other factors as:

- Influence of (flowing) groundwater
- Quality / thermal conductivity of the grouting
- Depth of the BHE
- Depth of the casing

Beside the data from the TRT also temperature profiles performed before and after the test can be used for acquiring further information.

The working principle of a TRT is the following:

- The TRT-rig is connected to the BHE and water will be circulated in the system (figure 1).
- A constant heat injection is provided by a heater (electric resistance, gas, or heat pump).

  The thermal energy is transported with the water and introduced into the ground. From the development of the temperatures (response of the underground to the heat injection, fig. 1) the thermal conductivity can be calculated.

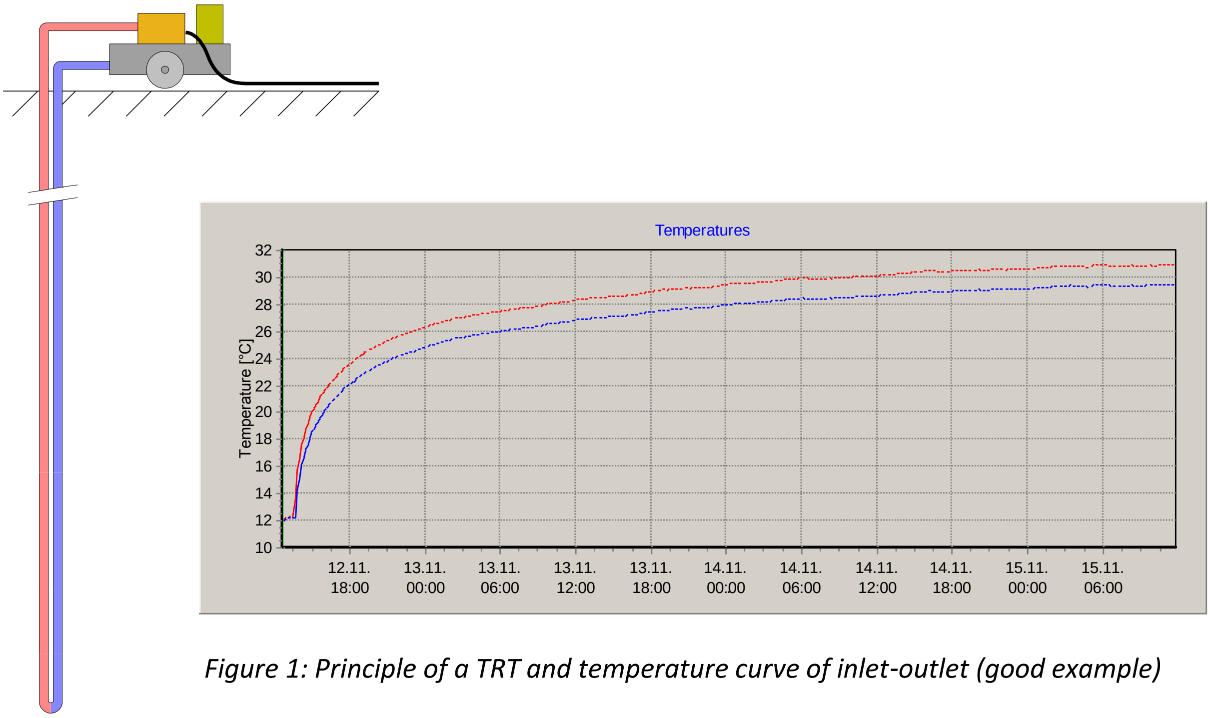

Figure 1: Principle of a TRT and temperature curve of inlet-outlet (good example)

2. Components of a TRT

Borehole heat exchanger (BHE):

- The depth and type of the test-BHE should be the same as the rest of the BHE-field is planned to be. It can be later part of the final system.
- For the evaluation of the TRT the exact specifications of the BHE must be known:
  - Depth of the BHE
  - Diameter of the borehole
  - Diameter and depth of the casing
- BHE must be filled with water
- Between completion of BHE and start of the TRT the ground should have time (~ 5 days) to recover to (quasi-) undisturbed conditions and to allow for (almost) setting of the grouting.

Electric Power Supply:

- Heat injection should result in a temperature change that is in the order of the planned operating range. With a too small temperature change, the signal will be low and thus the error in evaluation larger, while with too high temperature change, effects not present in the normal operation range might occur (e.g. drying). Depending on the expected thermal conductivity, a good value for a standard TRT can be around 50 – 80 W/m. Thus for a BHE of 100 m an electric power supply of 5 to 8 kW is required.

- A minimum electric power of ~400 V at 16 A is recommended, and power supply needs to be as constant as possible (less than 5% fluctuation over the test duration). In particular at a large construction site with a temporary power supply fluctuations can be substantial.

- Power supply should be without interruption – this sounds trivial, but can be a challenge for the duration of several days.

Hydraulic Unit:

- Preferably electric resistance heater with adjustable heating load up to approx. 10 kW.

- Circulation pump with adjustable pumping rate. Flow in BHE should be turbulent, pumping rate should be between 1,0 and 2,0 m³/h in most cases.

- Safety installations to protect test device:
  - Temperature limitation
  - Flow control

Data acquisition:

- Temperature in forward and return flow (as close to the top of the BHE as possible for accuracy, with the recommendation for a second set inside the TRT-rig, in case the ones at the BHE got interrupted). The accuracy of temperature measurement should be at least 0,1 K, better 0,01 K

- Flow rate (total water volume); the accuracy of flow rate measurement ought to be at least 10 litres, better 1 litres

- Heating load (total heating work), as close to the BHE as possible, in order to reduce the external influences

- Max. recording interval: 10min

- Additional data like ambient air temperature can help in interpretation of the results

3. Some Examples of TRT-rigs and practical Recommendations

Figure 2: The first UBeG TRT-rig: left for the first TRT done in Germany in 1999 (Sanner et al. 1999), right with a generator at a site without electricity)

Figure 3: TRT-rig of a new generation, mounted on a crawler for easy transport in a van and better access to the BHE on site

Figure 4: When setting up a TRT, the length of connection pipes between BHE and TRT should be as short as possible, and the BHE and connection pipes must be well insulated; to the left a correct setup, to the right an inappropriate setup from a SE-European site

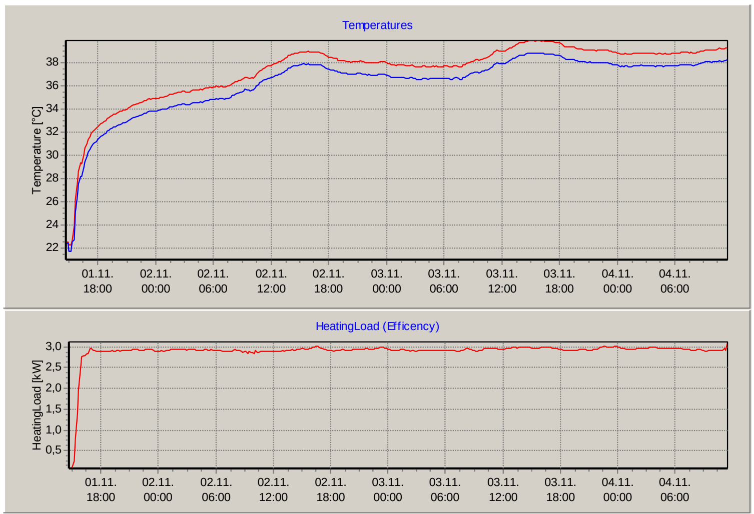

Figure 5: Result of inappropriate setup, with large temperature fluctuations at rather steady heat load

Figure 6: Make sure that there is no drilling work near the test-BHE. Preferably there is no drilling during the test at all. The drilling in near surroundings may induce a groundwater flow that disturbs the TRT

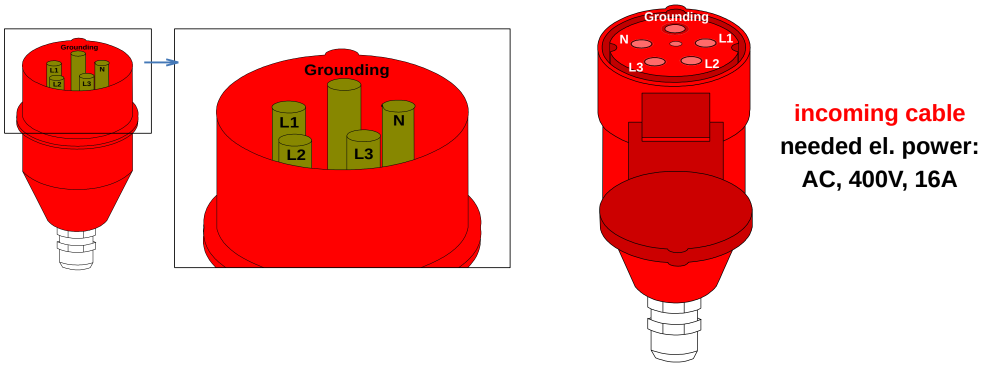

Figure 7: Before connecting the TRT to the power supply, check the phases!

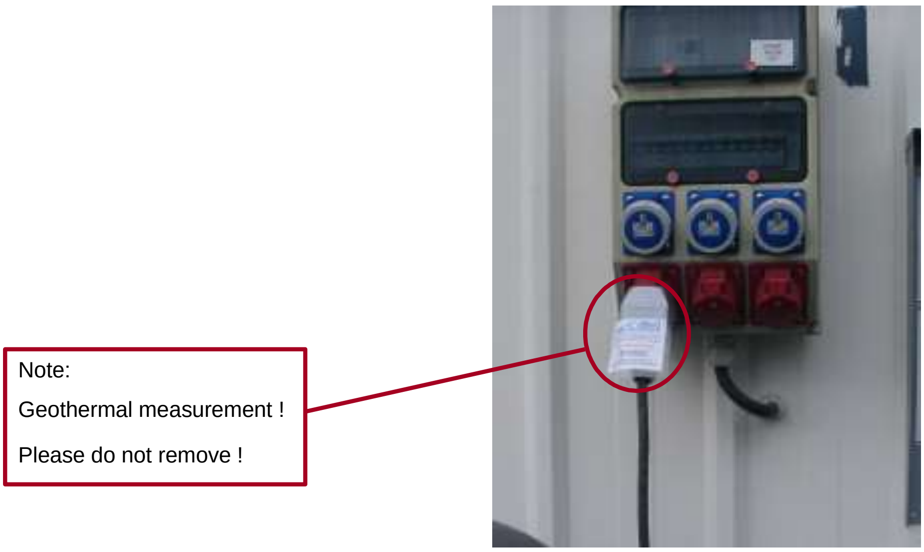

Figure 8: Make sure that no one interrupts your power supply. Sometimes simple things are of great value!

4. Evaluation of a TRT

While setting up and running a TRT might be a task for drillers (or at least require their cooperation), the evaluation of the test usually is done by a designer with specific experience. Thus in this subchapter only an overview of the evaluation is given, with the aim to help understanding why some parameters like constant heat or exact knowledge of BHE-length are so important. The simplest method for evaluation of a TRT is based on Kelvin´s Line Source Theory:

$$\Delta T_{(r_b,t)} = \frac{q}{4\pi\lambda H}\int_{p}^{\infty}\frac{e^{-\beta^2}}{\beta}d\beta$$

$$p = \frac{r}{2\sqrt{\alpha t}}$$

α = thermal diffusivity [m²/s]	β = integration constant
H = length of tube [m]	t = time from the test beginning [s]
q = heating load [W]	ΔT = temperature difference [K]
r_b = radius [m]	λ = thermal conductivity [W/m*K]

For the practical use, an approximation of the Line Source theory can be applied, as suggested by Eklöf & Gehlin (1996):

$$\lambda_{eff} = \frac{Q}{4\pi Hk}$$

with:			
	k	[-]	gradient temperature versus logarithmic time
	Q	[W]	Heat injection (Heating Output of GeRT)
	H	[m]	Length of BHE
	λ_{eff}	[W/mK]	Effectiv thermal conductivity

only valid if

$$t > \frac{5r_0^{\,2}}{\alpha}$$ (Lower time criterion)

with:		
	r_0	radius of the borehole
	α	thermal diffusivity = λ / ρC_p
	ρC_p	volumetric heat capacity

The evaluation of a test in the year 2000, using this technique, is shown in Figure 9. The curves appear as straight lines in a semi-logarithmic scale, and the gradients can be interpreted statistically (after deleting the first part of the curve before the lower time criterion). Inserting the values for the gradients and for the other variables (H = 70 m, Q = 3350 W) results in the following equations:

T1 $$\lambda_{eff} = \frac{3350}{4\pi 70 \cdot 1{,}801} = 2{,}11$$

T2 $$\lambda_{eff} = \frac{3350}{4\pi 70 \cdot 1{,}809} = 2{,}11$$

Chapter 8

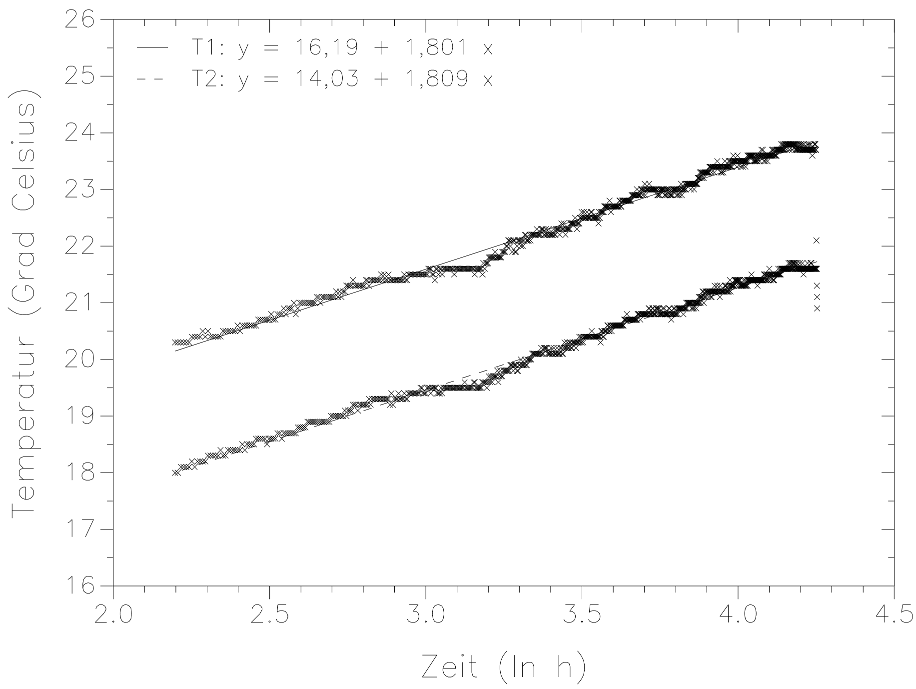

Figure 9: Data from an early TRT shown on a semi-logarithmic scale

With the so-called "Stepwise Evaluation" an evaluation of the recorded data with a fixed start time and increasing length of the data set until the full duration to the end time is performed. The resulting thermal conductivity for each time-span can be calculated and plotted over time. This procedure is a useful tool to check the quality of the data collected and the validity of the results.

Usually in the first part of such a curve the thermal conductivity swings up and down, converging to a steady value and a horizontal curve in the case of a perfect test (figure 10, top).

With substantial influence of flowing groundwater, the curve rises upwards steadily after some time (figure 10, middle). Thus the Test result (l) is determined by the duration of the test, and the longer the testing time is, the higher the l will be. There is no result for such a test. In case of influence of fluctuating power supply or environmental influences (e.g. solar radiation), the test result is not stable, and testing time must be extended (figure 10, bottom).

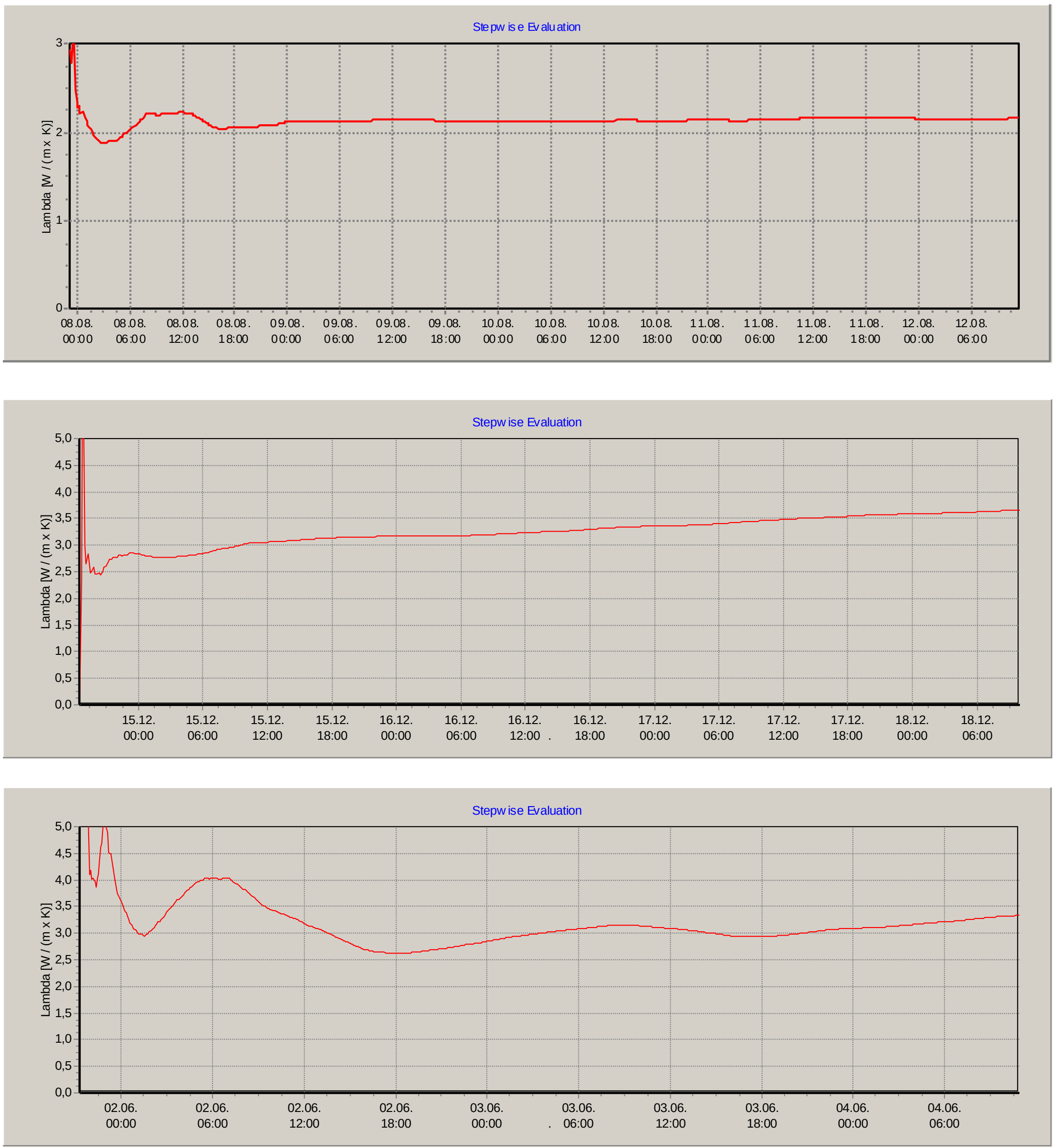

Figure 10: Examples of stepwise evaluation of TRT: Dominated by conductivity, good reliability (top), dominated by advection and not usable (middle), and high fluctuations and low reliability (bottom)

In a number of cases evaluation with the line-source method is simply not feasible. With parameter variation (figure 11) it is possible to evaluate only parts of the temperature curves, and the technique is also a helpful tool to find solutions for unclear situations (ground water influence, power fluctuations, environmental influences etc.). The parameter variation shown in figure 11 was done software-based (GeRT-Cal) using an analytical solution. For more difficult cases sometimes a parameter estimation with numerical modelling might be the only way and should be done by experienced designers only.

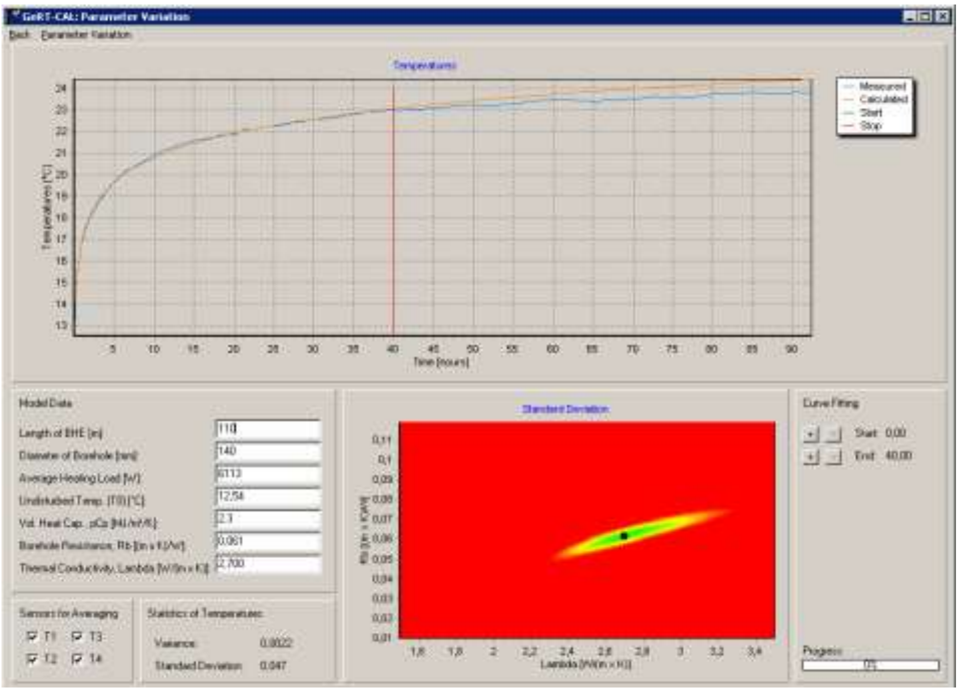

Figure 11: Parameter variation for TRT data (search for the “best fit”), with a linear area of good fit (green area)

The thermal borehole resistance r_b can be determined using the following formula (the values given as example are from the same TRT from 2000 as figure 9):

$$R_b = \frac{H}{Q} \cdot \left(T_f - T_0\right) - \frac{1}{4\pi\lambda} \cdot \left(\ln(t) + \ln\left(\frac{4\alpha}{r_0^{\,2}}\right) - 0{,}5772\right)$$

with	Q	heat injection (W)	3350 W
	H	borehole depth (m)	70 m
	T_0	undisturbed ground temperature (°C)	11,4 °C
	l	thermal conductivity (W/m/K)	2,1 W/m/K
	a	thermal diffusivity, l/rc$_p$ (m^2/s)	9,1•10^{-7} m^2/s
	r0	borehole radius (m)	0,075 m

The value for rb is calculated with a number of values for:

t	elapsed time (s)
T_f	mean fluid temperature (average of T1 und T2 in fig. 9) (°C)

Time	Thermal Borehole Resistance
9 h	0,072 K/(W/m)
12 h	0,073 K/(W/m)
24 h	0,066 K/(W/m)
48 h	0,072 K/(W/m)
70 h	0,069 K/(W/m)

5. Temperature Measurement and Temperature Logs

The undisturbed ground temperature is an important design parameter, as it gives the background upon which all temperature changes due to heat injection or heat extraction need to be calculated. Undisturbed ground temperature may vary throughout Europe from a few °C above the freezing point in Northern Sweden to almost 20 °C in Southern Spain or in Greece. The measurement of undisturbed ground temperature can be done in the framework of a TRT in various ways.

One method – and the easiest of all – is to run the circulation pump at the beginning of a TRT and to measure the temperature development at inlet and outlet (fig. 12). An almost horizontal curve should be seen, with both values falling onto each other and giving the value for undisturbed ground temperature averaged over the borehole depth, and including any external influences as from groundwater. However, due to the (very small) heat input from the circulation pump, a small increase of the value might occur over time. An observation of temperature development without heating over some hours (as in fig. 12) also can help in detecting any residual heat from drilling or grout setting, given away by a temperature decreasing over time.

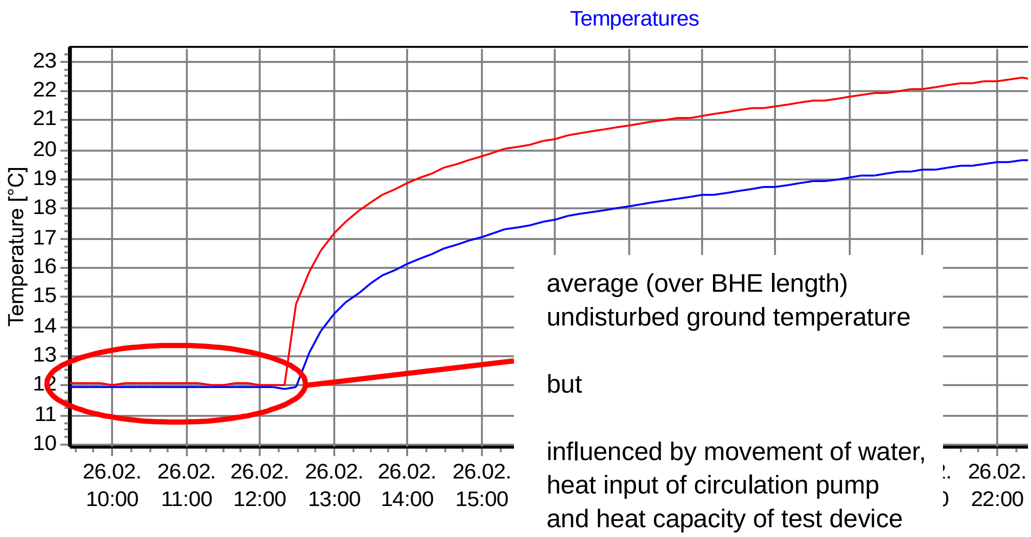

Figure 12: Measurement of undisturbed ground temperature by water circulation without heating

Another method which allows for exclusion of the zone of annual variation and which gives much more details that could be used for additional information is the temperature log. There are several tools available for taking a log, even inside a 32-mm-pipe as used for most BHE (fig. 13). Logging requires some patience to allow for full thermal equilibrium at each depth level to be measured, and some handling skills not to get a tool stuck in a well or pipe.

PT1000-temperature sensors

- Temperatur can be measured In real time
- quick measurement possible (low own heat capacity)
- often easy to put in but sometimes hard to retrieve

Device for measuring watertable and temperature

Pressure-/temperature loggers

- Automatic recording of depth, temperature and time
- For reviewing the date the device must be retrieved
- Measurement needs longer time because of heat capacity of device

Figure 13: Tools for taking temperature logs in boreholes and inside BHE-pipes (depending on diameter)

With the date obtained from logging, the temperature curve with depth can be drawn (fig. 14). In a perfect example as shown in fig. 14 the average undisturbed ground temperature can easily be determined, as well as the geothermal gradient (values from example in fig. 14):

$$Gradient = \frac{2{,}4K}{70m} \cdot 100 = 3{,}4 \frac{K}{100m}$$

If the geothermal heat flux is known, the thermal conductivity can be calculated using the geothermal gradient and vice versa: Heat flux = gradient x conductivity

However, in many cases the curves are all but clear. In the North of Europe frequently the influence of the last ice age can be seen in a colder region at some 20-40 m depth, groundwater flows can mask the gradient, and logs from boreholes in areas with dense, older building can show substantial influence from the buildings, sewage, etc.

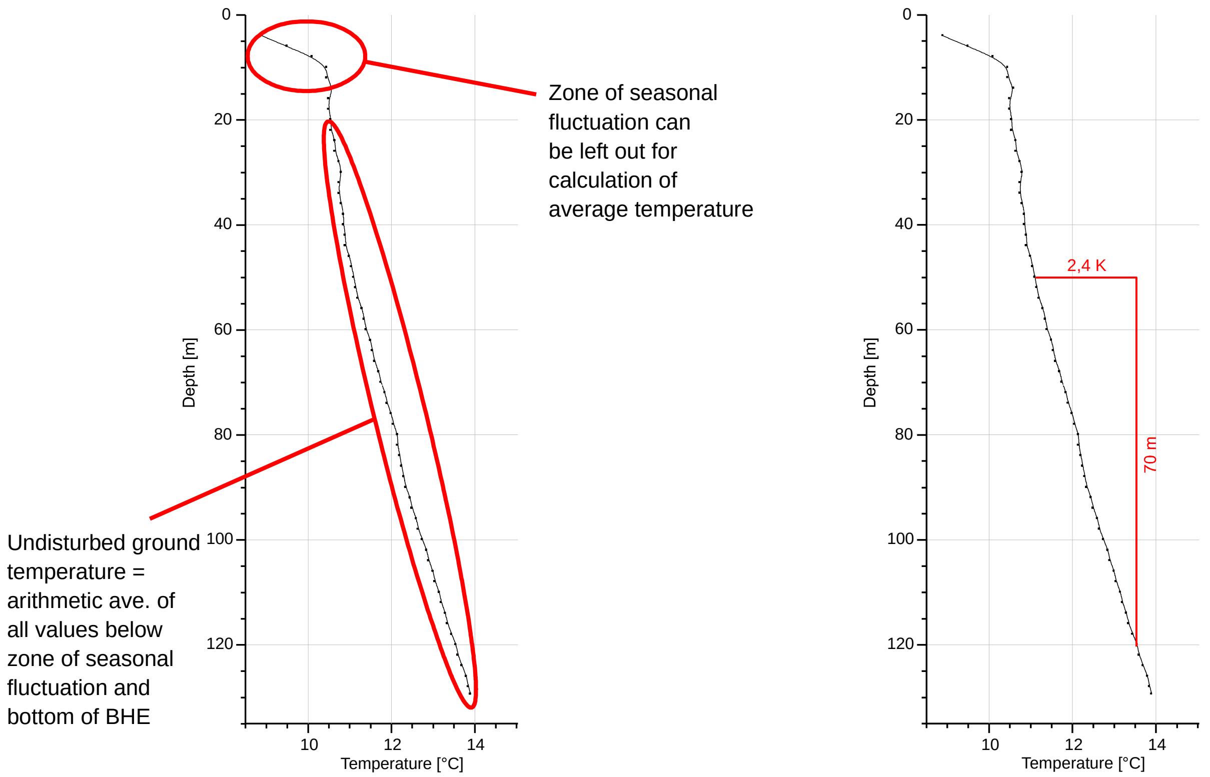

Figure 14: Temperature log and evaluation of average undisturbed ground temperature (left) and geothermal gradient (right, see text)

The temperature log before the test as shown in fig. 14 should be complemented with temperature logs after the end of the TRT (a recommendation could be a log directly after, one about 1 hour later, and another one 2-3 hours after the end of the test). These logs will show the gradual cooling of the fluid inside the pipes and allows for various conclusions as shown in figure 15. It should be noted that the exact time of the temperature measurement is not the same over the depth of the BHE, as the logging takes some time (up to 30 minutes for 100 m). So the signals might by slightly different with depth.

Among the features visible (cf. fig. 15) are groundwater flow, missing grout (to cool down so quickly the BHE must have a direct contact to flowing groundwater, i.e. not being encased by the grouting), or layers with different conductivity. Sometimes you don't know if you hit the bottom of the BHE with the temperature sensor, or if the BHE is just blocked (e.g. by a pinch). The "Bottom Heat Dissipation" gives a prove for having reached the bottom, as down there the heat is also transported in vertical direction downwards and a faster cooling can be seen.

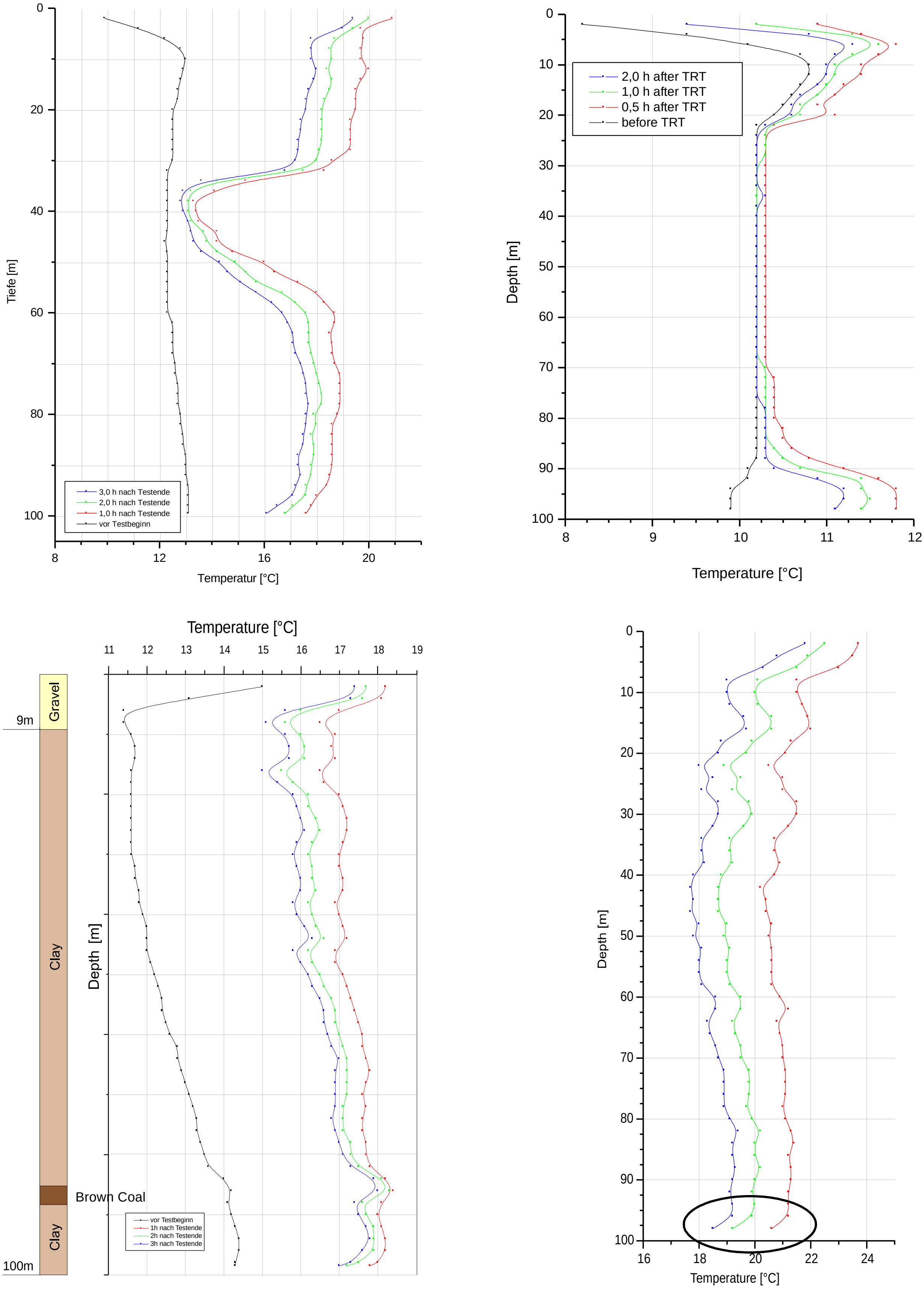

Figure 15: Features as elucidated by temperature log before and after TRT: Influence of groundwater-flow (top left), poor or non-existent grouting (top right), presence of a low-conductivity layer (bottom left), prove of final depth (bottom right)

6. Determining true BHE depth by Thermo-Impulse Method

Sometimes disputes arise on the question if the BHE actually has the full length as contracted. The TRT rig can offer a convenient method of determining the actual BHE-depth within a narrow margin of error. The method is called Thermo-Impulse and was first published in Sauer et al. (2010). It comprises of the following steps (cf. fig. 16):

- A strong thermal signal (impulse) is injected into the BHE circuit
- The time the impulse needs to return is measured.
- With the (measured) flow rate and pulse-time-delay the volume of the BHE can be calculated.
- With the known diameter of the BHE tube and the volume the length can be calculated.

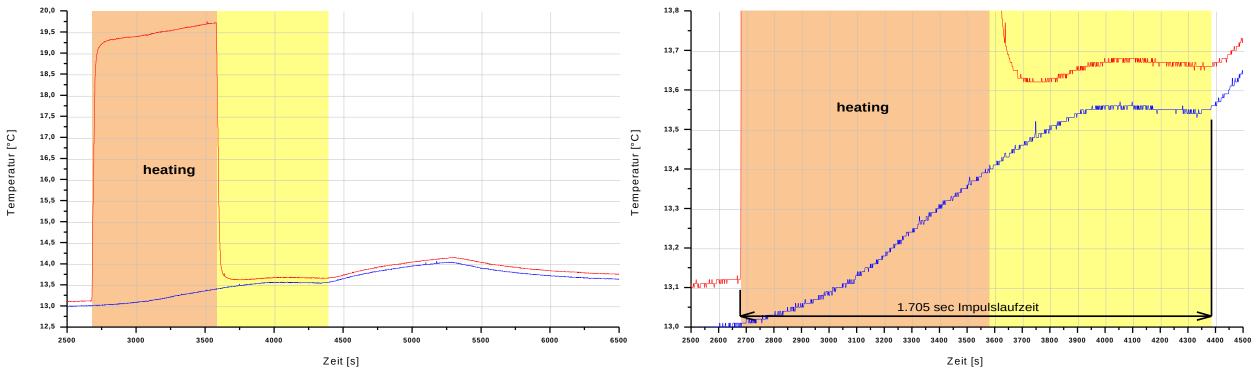

Figure 16: Principle of Thermo-Impulse method (recurrence of impulse)

Sample calculation for a BHE with double-U (4 x 40mm) and known depth of 295 m (cf. fig. 16):

Impulse	ca. 16 kW for 15 min
Pulse time delay (t)	1.705 sec
Ave. flow rate (Q)	2.0981 m³/h
BHE volume (Q x t)	0,9937 m³
BHE length (Vol. / (4πr²))	297,6 m
Dev. to real length	2,6 m (0,9 %)

The method can yield reproducible results within an error margin of less than 1 % of the BHE length. For example, three consecutive measurement where made on a BHE 130 m deep, using the same pumping rate, but a different duration of the heating impulse (fig. 17). The results obtained for the 3 measurements are given in table 1.

Measurement	Time delay to recurrence	Depth (m)
1st:	658 s	129,0
2nd:	662 s	130,2
3rd:	659 s	129,7
Average		129,6
Maximum deviation		1,0 m (0,8 %)

Table 1: Results of the 3 Thermo-Impulse measurements shown in fig. 17

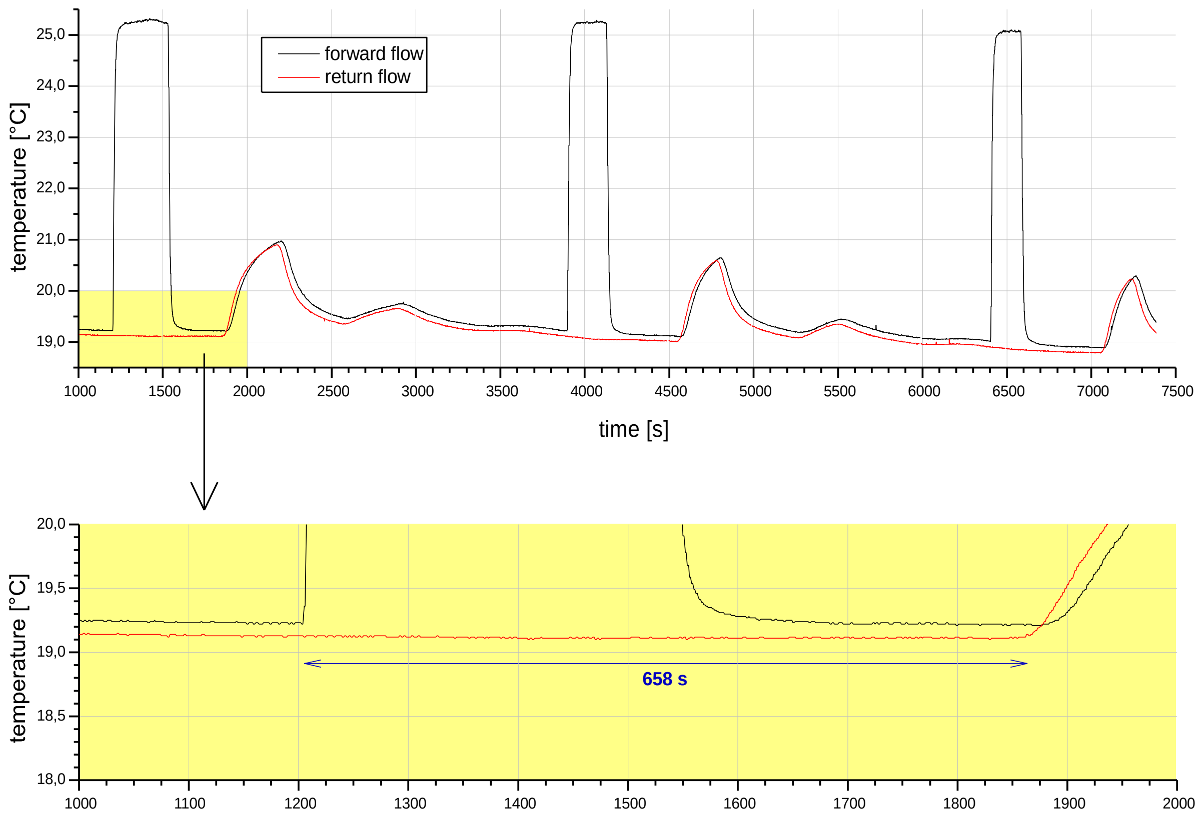

Figure 17: Reproducibility of Thermo-Impulse results

Literature:

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Chapter 9

Environmental concerns at the drill site

By Olof Andersson

1. Introduction

The main goal for using shallow geothermal systems is to provide all kinds of customers with space heating and cooling without using fossil fuels. In this sense the technology in it self should be looked upon as an excellent way of reducing the hazards with climate warming.

The most obvious advantages by using shallow geothermal are:

- Less emission of environmentally harmful flow gasses
- Less emissions of solids and micro particles that may cause health problems

However, constructing and running a geothermal plant may cause local environmental effects that have to be considered, and hopefully avoided by a proper design and careful construction.

2. Why should drillers and installers care about environmental concerns

Drilling boreholes contain a number of things that can go wrong and harm the local environment both on surface and underground. It is therefore important to at least make a simple risk analyzes and this way be prepared for both expected and unforeseen events that can occur during the construction.

3. General concerns

Closed loop systems will have an impact on the surroundings while the holes are drilled. A common concern is the noise related to run the rig and compressor or mud pump, but also the transports by trucks and handling of casing and drill rods. There may also be an impact from handling water or drilling mud. However, these items are normally taken care of according to local procedures and regulations.

Other types of environmental impacts are more connected to possible sub surface impacts in the form of disturbing the natural underground conditions. Common such concerns, for closed and open loop systems respectively, are listed below and should be a part of any driller's environmental quality control during drilling and completion of systems.

Closed loop systems

- **Contamination of the ground water by creating a conduct from the surface**
- **Contamination of ground water by boreholes penetrating several aquifers**
- **Contamination of the underground by leakage of heat carrier fluids**
- **Contamination of the soil by leakage of oil or chemicals used at drilling**
- **Freezing of boreholes penetrating clayey soil that is sensible for settlements**
- **Lowering the pore pressure in clayey soil by drainage that may cause settlements**
- **Drilling out cavities that may collapse and cause settlements or holes**

Open loop systems

- **Drawdown cones causing settlements in soils that are sensitive for compaction**
- **Pressure cones causing up lift phenomena and water damages to buildings, fauna and flora**
- **Contamination of the groundwater by substances from the surface**
- **Contamination by internally released substances or chemicals**
- **Contamination of the soil by leakage of oil or chemicals used at drilling**
- **Impacts on fauna and flora cased by a temperature interaction from below**
- **Change of bacterial growth and composition in the underground caused by changing the**

4. Special considerations

4.1 Working in water protected areas

Aquifers used for water supply will often be protected. In such areas special attentions must be given to installations of shallow geothermal systems in any country. As a matter in fact, an installation may even be denied by authorities. If not, there are in any case special rules that must be followed. There fore, and as a general recommendation: ***Always make sure to follow regulations related to water protected areas***

4.2 Hitting artesian water

Occasionally, and maybe unexpected artesian water may cause not only technical problems but also problems related to the local environment as shown in figure 1.

Figure 1. Example of artesian flow creating environmental problems

From a technical point of view a tight grouting in can be made if the artesian pressure is not to high by using packers and other forms of sealing equipment. However, there is always a risk for break through, if not through the grout itself, so outside the casing or in fractures closed by the borehole. For this reason the recommendations are:

1. Always seal artesian boreholes with a proper grouting job

2. Reconsider the design and change depth to end boreholes well above artesian aquifers

4.3 Hidden obstacles

The underground may hide several different structures and man made obstacles that must be regarded prior to drilling. Such "hidden risks" for a safe drilling may be cavities (as illustrated in figure 2), water and gas pipes or electric cables.

Figure 2. An undermined ground collapsed and caused damages

There may be a number of hidden obstacles, especially in urban areas, that may cause damages to the environment and that in some cases also are connected to health risks. Therefore, ***Always make a survey on potential hidden structures, such as pipes and cables before starting a drilling operation***

Section C: Specific Items for Closed Systems

Chapter 10

Design of borehole heat exchangers

By Burkhard Sanner

1. INTRODUCTION

A borehole heat exchanger (BHE) is meant to carry a fluid inside the underground and allow for exchange of heat from the underground into the fluid (heat extraction, heating mode of the system) or for exchange from the fluid into the underground (heat injection, cooling mode of the system). The BHE consists of pipes containing the fluid; because it needs to be installed down to a certain depth, it is typically long and slim. The BHE must include a design for the return of the fluid from the deepest point in the borehole back to the surface.

The different methods of coupling the fluid circuit inside the BHE to the heat pump are shown in Chapter 1, Figure 3. Because of the need to circulate a fluid down into the earth and up again, there are only a few basic options for BHEs:

- Coaxial (or concentric) pipes, also known as pipe in pipe
- U-pipes (two or more simple pipes connected at the bottom)
- Only for heat pipes (see Chapter 1, Figure 3). A single pipe is sufficient, as the vapour can rise upwards in the centre of the pipe while the condensate flows down along the pipe walls.

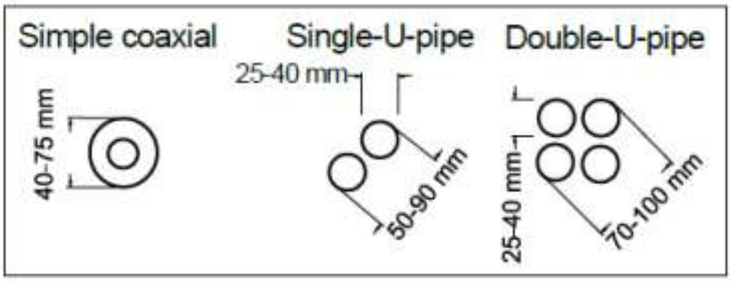

Figure 1. Cross sections of three most frequent BHE types

The effectiveness of BHEs can be described using a summary parameter, the borehole thermal resistance Rb. This parameter includes all the heat transfer phenomena from the ground outside the borehole right into the fluid inside the pipes (Fig. 2). For BHE design, only these parameters can be influenced by engineering, as the ground outside the borehole cannot be changed.

The maximum efficiency of a BHE under given load circumstances (i.e. permissible temperature difference ground-fluid and planned operation time) can be calculated and plotted against Rb (see Chapter 1, Figure 8). So the quality of a BHE type can be benchmarked using Rb and the Hellström-efficiency ηH. It depends mainly on pipe material, pipe size, pipe configuration, and filling of the annulus.

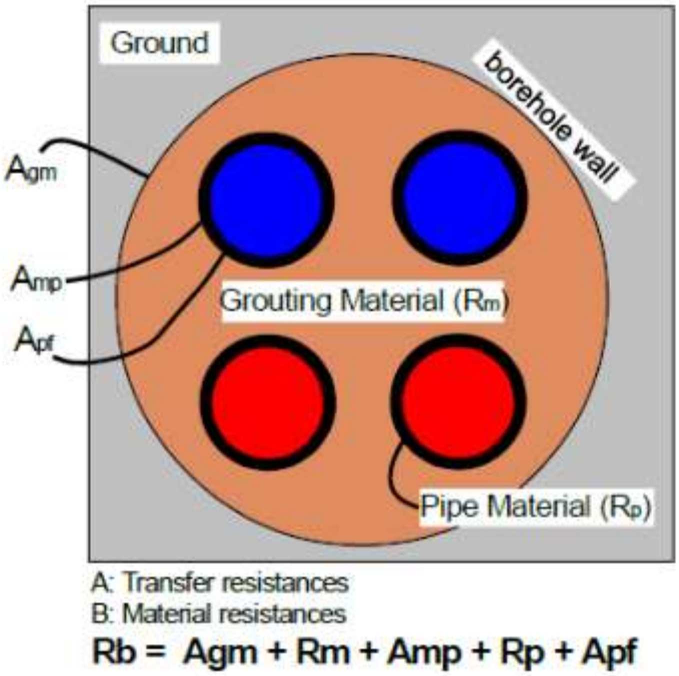

Figure 2. The components of Rb shown in the cross sections of a double-U-BHE

For sizing of BHEs to a given heating and/or cooling load, different methods are available both for smaller and larger projects. For smaller systems such as in single-family-houses, design is done using tables or nomograms (e.g. VDI 4640 or SIA 384/6), or calculations with easy-to-use software. For larger systems, design calculations with simple software like EED or even with numerical simulation is required. The boundary between small and large typically is set at about 30 kW thermal capacity.

Chapter 11

INSTALLATION AND GROUTING

By Walter J. Eugster

1. INTRODUCTION

Installing the Borehole Heat Exchanger (BHE) and grouting the borehole have the same importance for the completion and the future operation of the system as the drilling itself or as connecting the BHE to the Heat Pump (HP).

The following key points ensure a good job:

- The borehole must be kept open until grouting has finished. Thus any auxiliary casing is removed after grouting
- The BHE tubes need very careful handling during transport, on-site storage and installation
- Grouting needs special attention and care. These are the three main functions of the grout:
    - Sealing the borehole to inhibit any vertical water flows along the BHE (groundwater protection function)
    - Ensuring a good thermal contact between the BHE walls and the surrounding underground (thermal function)
    - Protecting the embedded BHE tubes from mechanical damage (technical function)
- The installing and grouting work is done by the driller. But the designer should know what to expect from this working phase.

2. INSTALLATION PROCEDURE

2. 1. Preliminary work

It is strongly recommended that some preparatory work is done before inserting the BHE into the borehole. The drilling staff may do this step during the drilling phase.

The BHE has to be mounted on and fixed to a decoiler (Fig. 1), if the BHE length is longer than 50 m. This avoids unreeling the BHE on the ground of the construction site, which is a high risk for any mechanical damage to the BHE. If the BHE is longer than 150 m the decoiler is preferably equipped with a brake to ensure a slow and careful insertion into the borehole.

The BHE tubes need a visual check to detect damage. For PE100/PN16/SDR11-tubes, notches and damage of max. 10% of the tube wall thickness are acceptable.

It is also recommended that a first tube tightness check is performed using air at about 6 bar to detect damage, especially when the transportation of the BHEs to the construction site and/or the storing of the BHEs on site were not made under the supervision of the drillers.

Then additional weights are normally fixed at the BHE foot and the injection tube is fixed to the BHE near to the foot.

Remember: use, preferably, factory welded BHEs. If the foot is welded to the BHE on the drilling site, the driller needs a valid welding certificate.

Figure 1. BHE on a decoiler during the first density test using air (picture: Polydynamics Engineering Zurich)

Figure 2. Ready-to-insert BHE with an additional weight, protected foot and a fifth injection tube

2. 2. Insertion of the BHE

The BHE is inserted as vertically as possible (Figs 2 and 4) into the borehole. Some drillers use guide rollers to ensure this. The sharp casing endings should be protected to avoid BHE damage through abrasion (Fig. 3). The BHE is moved carefully, slowly and with speed control into the borehole.

The pressure conditions inside/outside the BHE tubes need special attention during insertion:

- BHE must be filled with water if there is water in the borehole

- Be aware of the following limits for PE100/PN16/SDR11 tubes:

  Dp (inner à outer): max. 21 bar

  Dp (outer à inner): max. 8 bar !!

  If this value is exceeded the BHE starts to collapse!!

After complete insertion, the BHE is cut to the required length (often BHEs are only available at certain specified lengths).

In preparation for the grouting, the BHE is then completely filled with water (Fig. 5), a primary pressure is applied and the BHE is hermetically sealed (valve). The pressure limits for the tubes must be taken into account.

Figure 3. Two different casing ending protectors (picture: Polydynamics Engineering Zurich)

Figure 4. Guide rollers to ensure vertical insertion (picture: Polydynamics Engineering Zurich)

Figure 5. Cut the tubes to required length, fill them with water, apply a first pressure and seal them

3. GROUTING

The grouting material itself has to fulfil a number of specifications, given by the local authorities or by professional associations.

The following material characteristics may be regulated:

- Minimal Density of the grouting suspension
- Minimal stability of the suspension
- Minimal compression strength of the hardened backfill material
- Maximal hydraulic permeability of the hardened backfill material
- Optionally a minimal thermal conductivity
- Optionally a minimal resistance against structural damage after several freeze-thaw cycles.

Figure 7. During grouting the auxiliary casing still prevents the borehole from collapsing. The BHE is under pressure (picture: Polydynamics Engineering Zurich)

Figure 6. Various types of grouting equipment (pictures: Polydynamics Engineering Zurich)

Industrially fabricated and bagged backfilling material with a constant blending and controlled quality is the preferred solution. Self-made mixtures on the drilling site never have the same constant quality as industrially blended materials.

Grouting material is either mixed in tanks of a given volume and then pumped tank by tank through the injection pipe into the borehole, or it is continuously mixed using a proportioning pump (Fig. 6). The quality of the grout suspension must be constant over the whole grouting procedure and has to be checked by density measurements.

To guarantee the groundwater protection features of the grout material, the driller has to follow exactly the manufacturer's mixing recipe.

The Borehole is grouted either using the previously fixed injection pipe or sometimes using metallic BHE mounting rods which then are removed rod by rod during grouting (Fig. 7). Basically and essentially, grouting must be done from the bottom to the top of the borehole following the so-called contractor process. The injection pipe is left in the borehole and the deepest rod must be kept below the grout material level over the whole grouting process. Grouting from the top using any buckets or pumping the suspension from the surface is not permitted.

The grouting process is finished, when the out-flowing grout suspension at the wellhead has the required quality. Now the auxiliary casing is removed and the BHE is prepared for final testing.

Note: To avoid uncontrolled gas or water outflow from the borehole, the grouting process has to take place immediately after inserting the BHE!!

Due to the limits regarding the pressure difference inside/outside the BHE, the following system limits and recommendations are given for PE100/PN16/SDR11 BHEs (Table 1).

Density of grout suspension	Allowed BHE length without reservation	Grouting only when BHEs are hermetically sealed	BHE length exceeds pressure limitations
1200 kg/m^3	up to 400 m	no limitation	no limitation
1400 kg/m^3	200 m	> 200 m	no limitation
1600 kg/m^3	120 m	120 – 340 m	> 340 m
1800 kg/m^3	100 m	100 – 260 m	> 260 m
2000 kg/m^3	80 m	80 – 200 m	> 200 m

Table 1. Technical limits for PE100/PN16/SDR11 BHEs

There are many different grouting materials on the market. Some of those have a higher thermal conductivity, others show a higher resistance against freeze-thaw cycles and others need only a short time until a rather high compression and/or shear strength is provided.

Therefore, there is a wide range of different products with different physical properties. It is up to the drillers or the designers to choose the optimal material for their purposes. In addition, of course, the price of the grout is an important criterion for the clients in an open market.

A higher thermal conductivity, for example, lowers the borehole resistance and increases the thermal capacity of the BHE. This is a big advantage especially in the cooling case. In the heating case, the total BHE length could be reduced under certain circumstances.

Both a higher thermal conductivity or a higher resistance against freeze-thaw cycles induce higher density of the grout suspension. This could lead to reaching the technical limits of the BHEs more quickly. It is moreover a question of the total system design.

4. TIPS AND REMARKS FOR DESIGNERS

Licensing authorities may impose special conditions regarding BHE quality, length, position, grouting, etc. – always follow these!

To avoid delays due to non-professional work, it is advised to contract only experienced, certified BHE drillers with nationally or internationally accepted well-known labels or certificates who will ensure:

- Skilled drilling staff to carry out the scoped work
- Suitable drilling expertise to deal with specific site geology and hydrogeology
- The use of drill rigs equipped with adequate safety equipment to detect, e.g., gas and artesian water outflows as well as drilling staff trained to face such incidents.

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Chapter 12

FUNCTIONAL AND QUALITY CONTROL

By Walter J. Eugster

1. SYSTEM CONTROL

Leakage, pressure, temperature (Fig. 1)

The Borehole Heat Exchanger (BHE) circuit must at the least be equipped with:

- Filling and flushing fittings
- A de-aeration device
- A pressure-relief valve
- A manometer
- A pressure control device
- An expansion vessel and preferably;
- An anti-icing control device (if no anti-freeze is added)

Temperature devices.

Each individual BHE circuit must be equipped with a flow control and shut-off valve to allow for adjustment of flow and pressure drop of each individual circuit.

Note: the natural expansion of deeper BHE tubes (forced by the weight of the fluid column at lengths >ca. 250-300 m) could exceed the calculated ordinary expansion vessel volume. This effect depends on the grout material.

2. TESTING, COMMISSIONING AND DOCUMENTATION

2.1. Final testing

The final testing of a BHE consists of two stages:

- a flow test
- a leak tightness test (pressure test).

Before performing the tests, it is necessary to flush the BHE tubes (Fig. 2), preferably from both sides, to clean the BHE and flush out dirt or any other remains in the tubes.

a). Flushing the BHE

Fresh water is pumped through each BHE circuit to flush out any dirt particles, preferably from both sides, until each circuit is completely flushed once.

b). Flow test

The aim of the flow test is to prove that the tested BHE circuit does not have an increased pressure drop, i.e. an increased hydraulic resistance (Figs 3, 4).

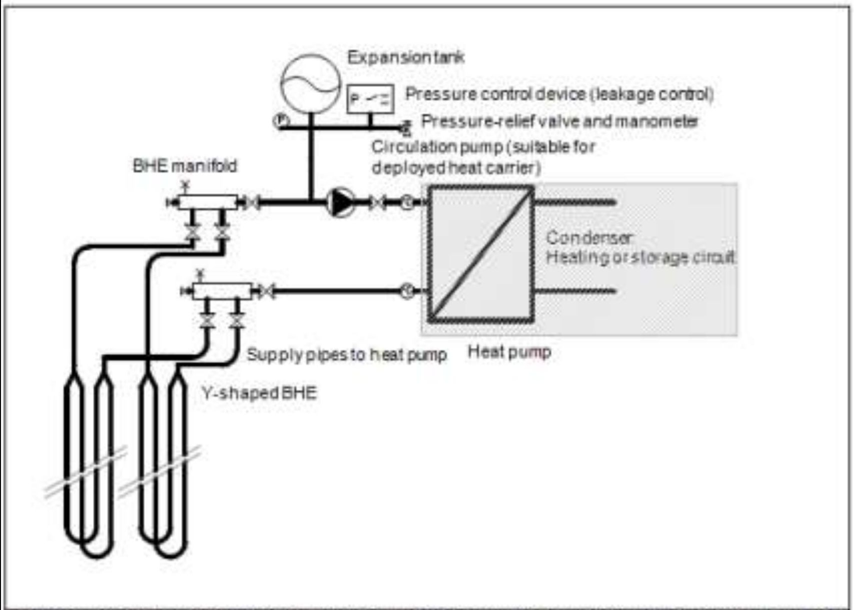

Figure 1. Example of a minimal equipment of primary circuits featuring 2 BHEs (drawing from SIA 384/6 (SN 546 384/6))

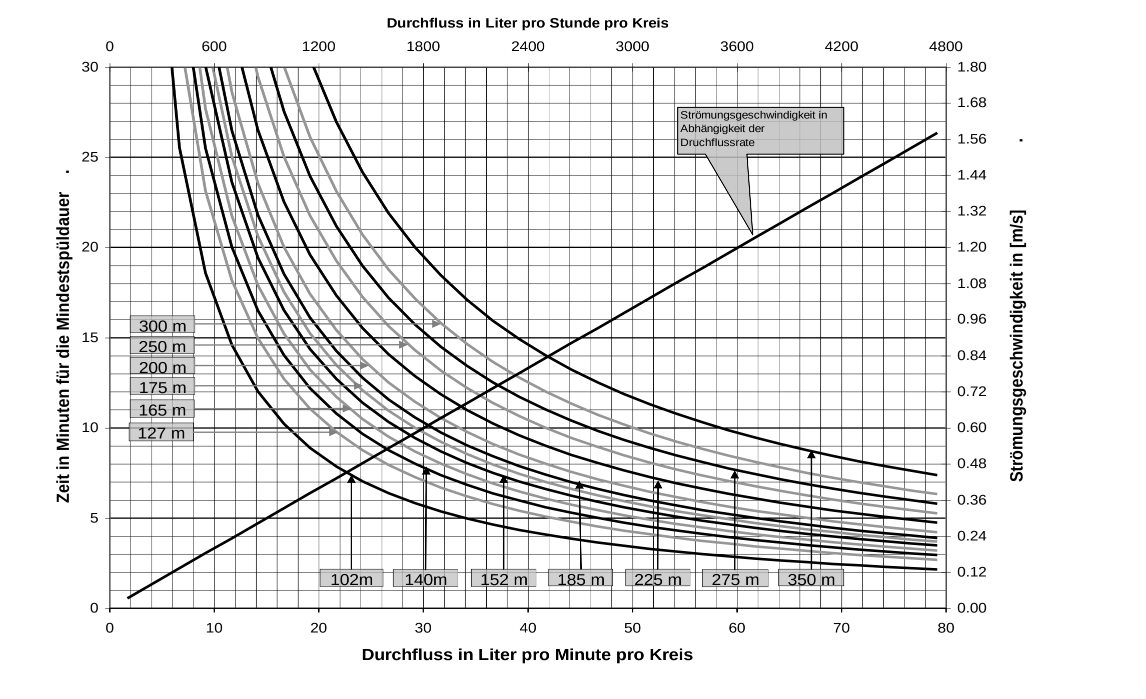

Figure 2. Example for the minimal flushing duration per circuit for a BHE tube Ø 40x32.6 mm as a function of the flow rate and the BHE length (graph from SIA 384/6 (SN 546 384/6))

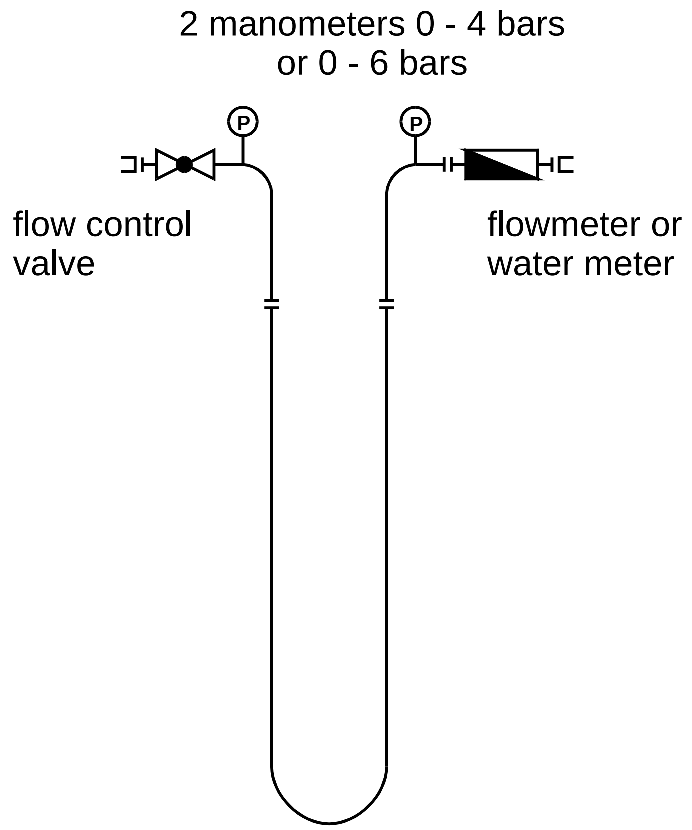

Figure 3. Flow test configuration (graph: Polydynamics Engineering Zurich)

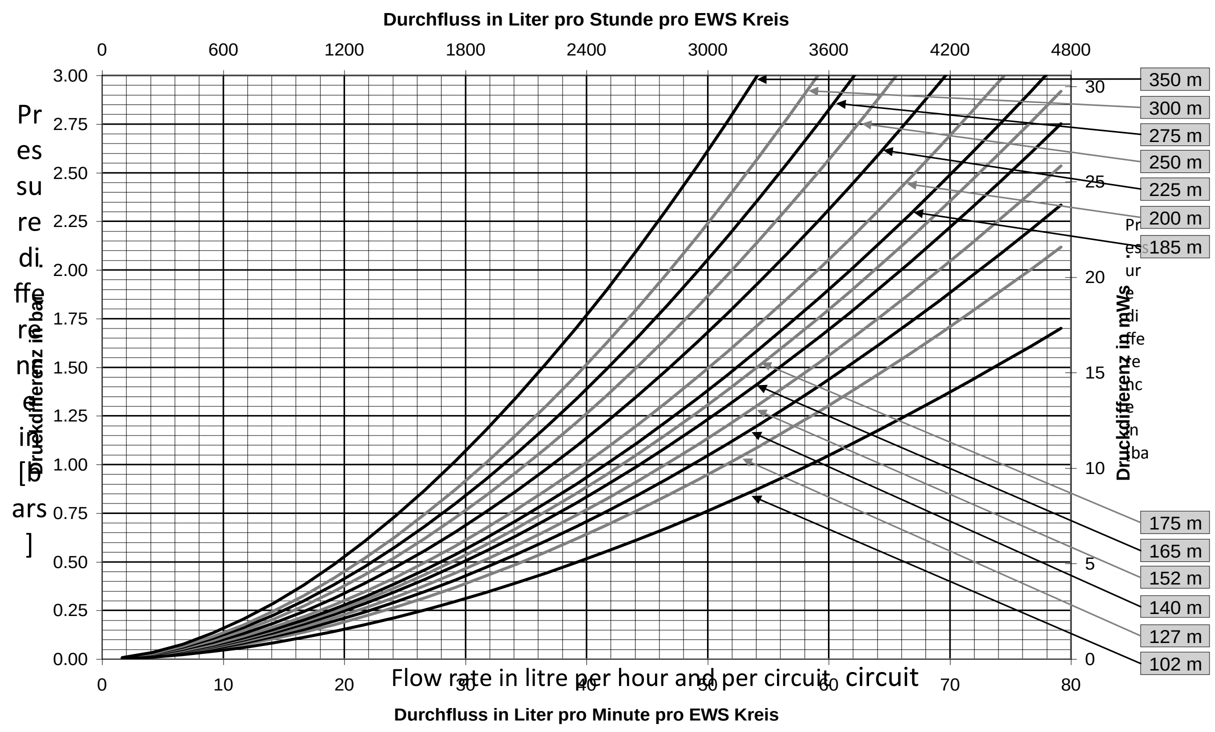

Figure 4. Theoretical maximal allowed pressure drop per circuit of a BHE, tube Ø 40x32.6 mm (graph from SIA 384/6 (SN 546 384/6))

A slight overpressure (outside à inside) during installation may deform the BHE tubes to an oval shape with a smaller sectional area. This effect increases the pressure drop. Possibly a larger circulation is then needed to ensure the projected flow rate.

The pressure difference (inflow – outflow) at constant flow rate must not exceed a certain theoretical value. The flow test may be combined with the tube flushing.

The equipment needed to perform the flow test is as follows:

2 manometers (0 - 4 or 0 - 6 bar)
1 flow control valve
1 flow meter (an impeller water meter is sufficient).

c). Leak tightness test (pressure test)

Leak tightness (pressure) testing has to follow the EN 805 prescriptions. For polyethylene (PE) tubes, the pressure testing has to be carried out as a 'compression test'. An overpressure (inside à outside) is applied to the pipe over the whole length. This step inflates slightly the PE pipe over its whole length. Then a sudden pressure drop of around 10% of the testing pressure is applied (Fig. 5). This pressure drop allows the pipe to compress again. If the pipe is tight, a pressure increase is measured.

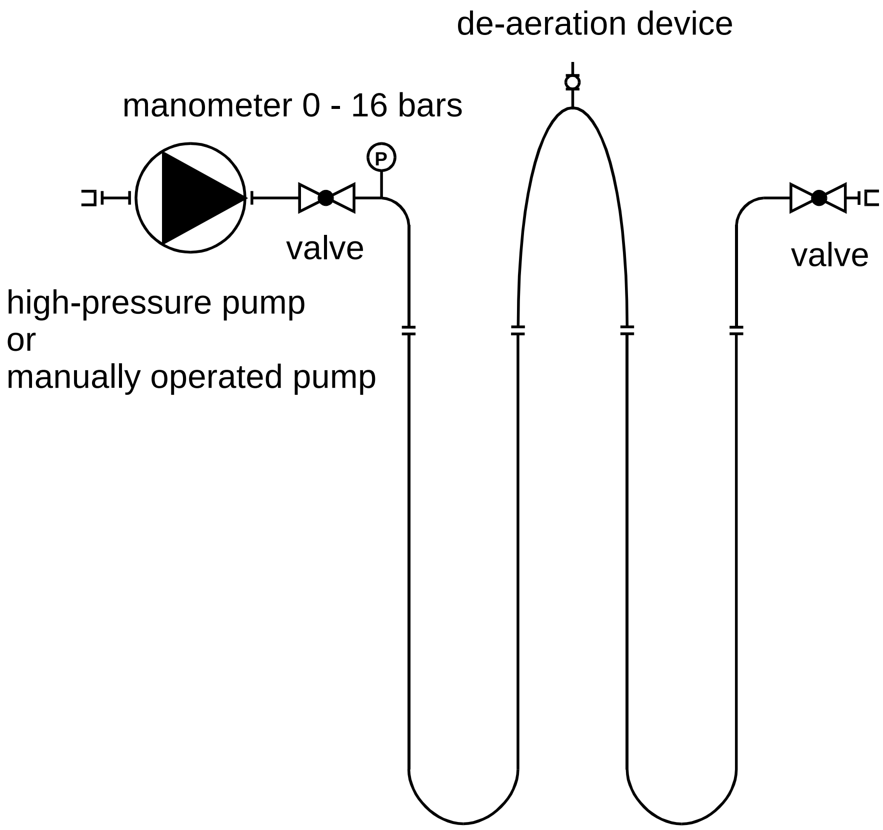

Figure 5. Leak tightness test configuration (graph: Polydynamics Engineering Zurich)

To perform such a test, the following equipment is needed:

- A high-pressure pump or a manually operated pump
- 2 stop valves

- 1 manometer 0 -16 bar
- A de-aeration device, if both circuits are tested at once
- This pressure test must be carried out immediately after having finished the grouting and when the grout material has still not hardened.

Test pressure for PE100/PN16/SDR11 tubes is recommended as follows after SIA 384/6 (SN 546 384/6):

- Overpressure at BHE foot: > 0.5 bar during testing
- Pressure at BHE heat: > 7.5 bar.

Test procedure in detail (Fig. 6):

- 1 h Idle period. No overpressure is applied to the tube 1
- Apply the test pressure. For PE100/PN16/SDR11 BHEs see Table 1. For other materials follow the manufacturer's specification 2
- 10 min Keep up pressure test 3
- 1 h Idle period. The tube is going to expand over the whole length
- Pressure measurement. The pressure drop may not exceed the manufacturer's specifications 4
- Sudden pressure drop of at least 10% of the test pressure 5
- 10 mins. First pressure measurement 6 A
- 20 mins. Second pressure measurement 6 B
- 30 mins. Third and final pressure measurement 6 C

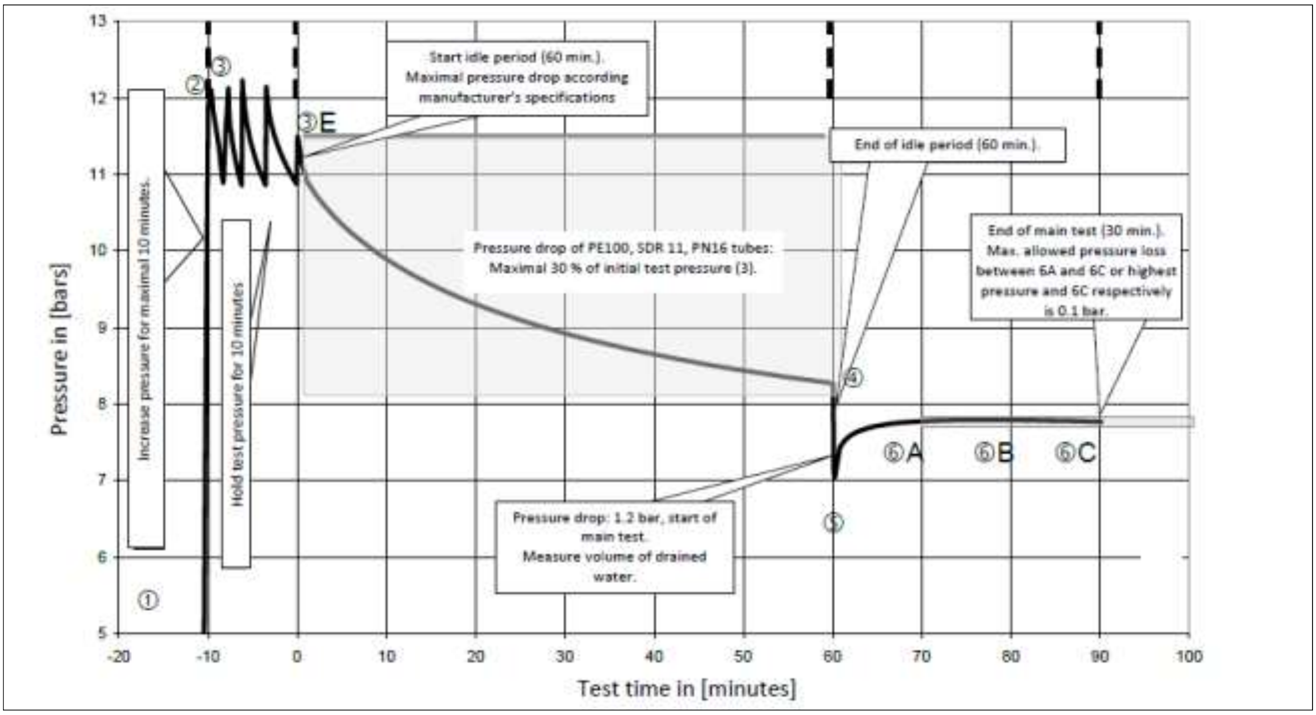

Figure 6. Graphical test procedure (graph from SIA 384/6 (SN 546 384/6)).

The BHE has passed the test if the pressure difference (pressure drop) between o C and

o A does not exceed 0.1 bars.

The upper part should not be filled up with water in cold weather, when there is a risk of freezing.

BHE length	Density of grout suspension				
	1200 kg/m^3	1400 kg/m^3	1600 kg/m^3	1800 kg/m^3	2000 kg/m^3
60 m	8.0 bar	8.0 bar	9.0 bar	10.0 bar	11.0 bar
80 m	8.0 bar	9.0 bar	10.0 bar	12.0 bar	14.0 bar
100 m	8.0 bar	9.0 bar	11.0 bar	14.0 bar	17.0 bar
120 m	8.0 bar	10.0 bar	13.0 bar	17.0 bar	21.0 bar
140 m	8.0 bar	11.0 bar	15.0 bar	19.0 bar	24.0 bar
160 m	9.0 bar	12.0 bar	17.0 bar	22.0 bar	27.0 bar
180 m	9.0 bar	13.0 bar	19.0 bar	25.0 bar	31.0 bar
200 m	9.0 bar	14.0 bar	21.0 bar	27.0 bar	34.0 bar
220 m	10.0 bar	15.0 bar	23.0 bar	30.0 bar	no BHE
	Test pressure for different BHE lengths and grout suspension densities.				
	No ordinary leak tightness testing. Testing only according to manufacturer's specifications.				

Table 1. Test pressure determination for PE100/PN16/SDR11 BHEs

(after SIA 384/6 (SN 546384/6))

After the final testing, the BHEs commonly are commissioned to the client (owner or installer respectively).

Figure 7. Protection of the BHE endings (picture: Polydynamics Engineering Zurich)

Figure 8. Example for sealing the BHE after final testing (picture: Polydynamics Engineer-

The final connection to the complete heat pump system could take place later – from a few days up to several months. Therefore, the BHEs have to be protected from any occasional damage during further construction work. The BHE endings are closed soundly and the BHE endings are marked and protected (Figs 7, 8).

3. COMMISSIONING

The final testing of the BHEs represents the commissioning of the BHE drilling work. The client should receive an invitation to attend the final testing. All driller logs and test records are handed over to the client.

This is the moment, the driller hands his responsibility for the BHEs to the customer and the legal warranty starts to run.

A final commissioning takes place when the complete heat pump (HP) system is finished. This includes at least the following points:

- Leak tightness test of the complete hydraulic system
- Check system temperatures, pressures and flow rates
- Check the function of each device
- Run the heat pump system
- Hand out a complete documentation to the customer
- Instruction of the future system operator in using and maintaining the system and what to do in case of a disruption.

4. DOCUMENTATION

If there are no relevant national regulations, at the least the following data have to be attached on site (heat pump) and documented in the project papers:

- Year of construction
- Drilling company
- Number, length and distance of the BHEs
- Length and diameters and supply/return pipes between heat pump and BHEs
- Brand, exact product description and mixture of heat carrier
- Volume of BHE circuits
- Flow rate and delivery height of the circulation pump(s)
- Brand and exact product name of the HP
- Heat and refrigeration capacity of the HP at design temperature.

The following additional data should complete the project papers:

- Drilling log and profile and – if applicable – the geological expertise
- Site map with exact (measured) location of the BHEs and the supply/return pipes
- Calculated capacity of the BHEs (dimensioning)
- Final test logs and records of delivery (commissioning).

5. MAINTENANCE

In principle, a BHE installation is maintenance-free! Nevertheless, a few points should be checked:

- Measure or look up the system pressure (yearly by the operator). Note the value in a log file
- Record each addition of liquids (water or antifreeze, added volume, pressure before and after adding)
- Check the antifreeze protection of the heat carrier every 10 years.

6. MONITORING

System monitoring delivers the base of any future system optimization. The system control should record and preferably store the following system parameters:

- Total time of operation
- Minimal supply and return temperature of the BHE circuit
- Supply and return temperature of the heat/user circuit
- Optionally: electric power consumption.

If there is no automatic data logger, recall these values from the system control and note them in a log file.

For smaller installations, record or recall these parameters in the beginning on a daily or weekly basis; later on, a monthly or yearly recording/recalling is sufficient.

For larger installations, a more detailed and automatic monitoring is recommended.

Chapter 13

Type of aquifers and their properties

By Olof Andersson

1. Introduction

For open loop systems it is essential to have a basic knowledge on under which conditions groundwater will be found and what characteristics it have, such as type of aquifer, its geometrical features, its capacity and boundaries, the chemical composition, etcetera. Some of these factors are also essential for closed loop systems.

In detail and related to open loop systems the most important aquifer parameters and properties are:

- Geometry (areal boundaries and thickness)
- Static head (groundwater table or hydrostatic level)
- Groundwater gradient (to detect the natural flow direction)
- Hydraulic conductivity (permeability)
- Transmissivity (hydraulic conductivity x thickness)
- Storage coefficient (yield as a function of volume)
- Leakage factor (vertical leakage to the aquifer)
- Boundary conditions (surrounding limits, positive or negative)

2. Why should drillers and installers care about different boundaries

Regardless the type of project, a driller must always be aware of the possibility to hit ground water while drilling and it may even be the aim to find groundwater. In any case, groundwater will always be an important factor planning and executing almost any drilling operation. Since groundwater will influence on the way boreholes best are drilled without causing problems, a basic understanding is therefore of uttermost importance for any driller.

3. Type of aquifers

By definition groundwater can be found almost anywhere. The groundwater table is defined as the level under which all pores or fractures are water saturated, se figure 1

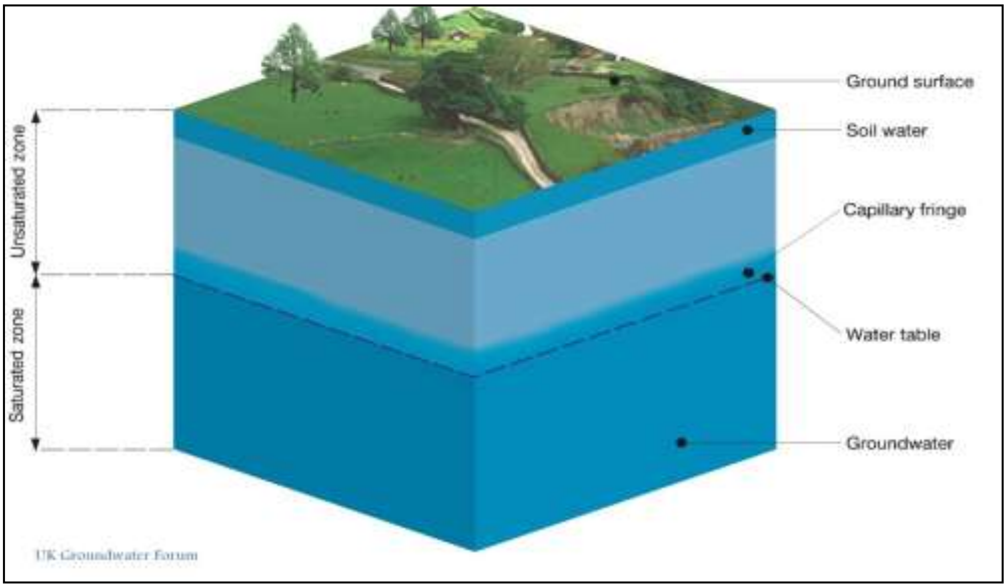

Figure 1. The saturated zone defines the groundwater table. An aquifer is in practice defined to be a limited geological formation from which ground water can be pumped by using water wells.

There are two types of aquifers. If the groundwater stands in direct contact with the atmosphere as in the figure 1, the aquifer is regarded as unconfined. If a permeable formation below the groundwater table is covered by a less permeable layer, the aquifer is regarded as confined, see figure 2. 7

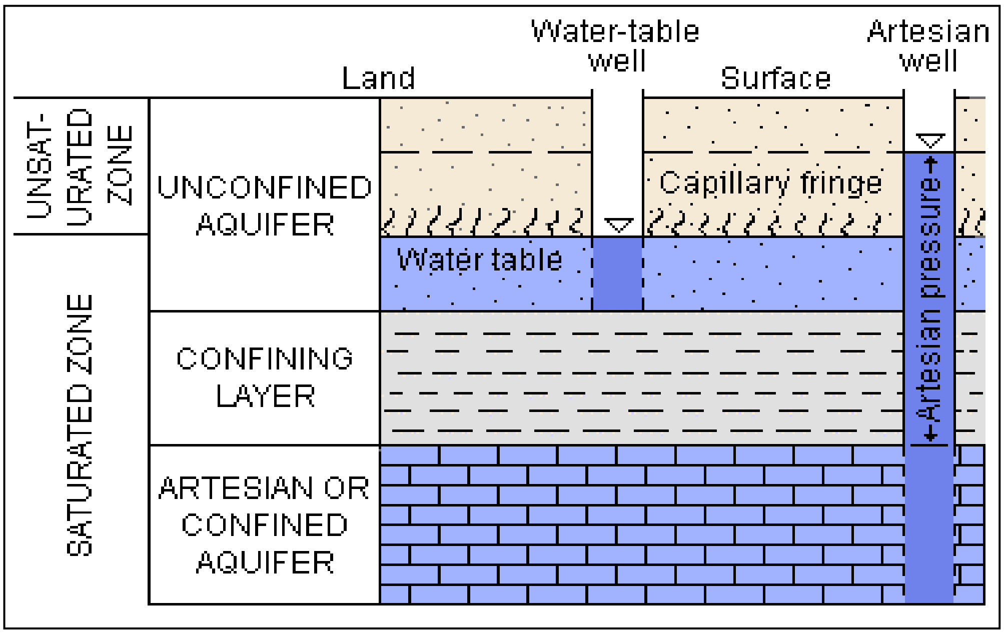

Figure 2. The types of aquifers unconfined with a free groundwater table and confined with a static head (artesian pressure).

The confined type of aquifer has a hydraulic pressure (static head) that is on a higher level than the top of the aquifer. The artesian pressure can sometimes reach above the surface level resulting in self flowing wells (artesian wells).

In nature, the groundwater is a part of the hydrological cycle. Hence, The groundwater is naturally recharged and drained. Sometimes the draining is shown up as springs, but more common it flows out to a lake or a river as illustrated in figure 3.

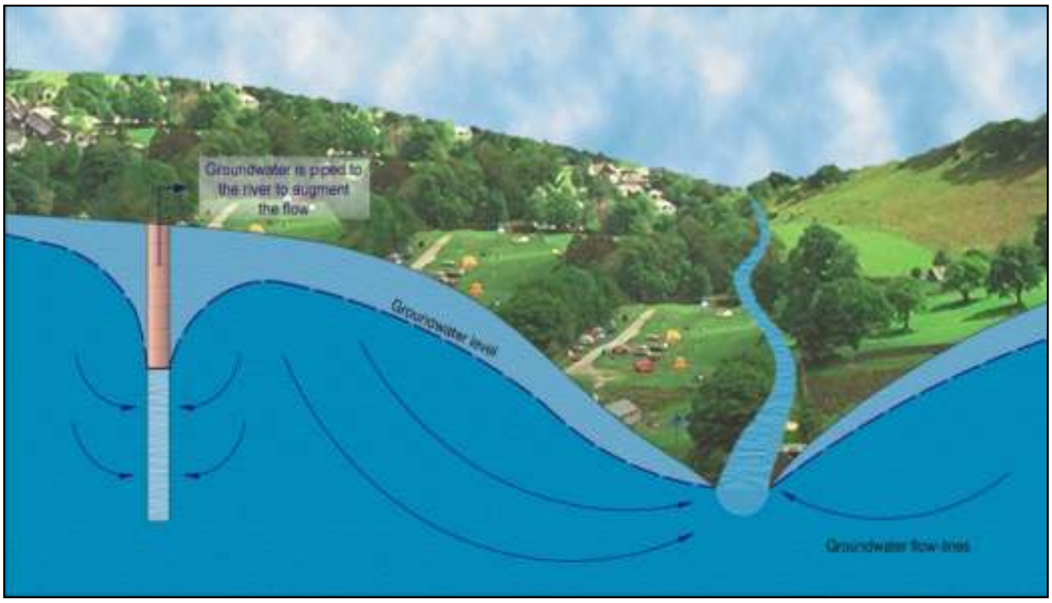

Figure 3. The flow of groundwater in an unconfined aquifer, in this case partly to a river and partly to a water well.

The figure also show how pumping of groundwater will create a cone of depression around the well. The size and shape of this cone is mainly related to the pumping rate and the hydraulic conductivity of the aquifer.

In the case of confined aquifers, the natural recharge and flow is more restrained compared to unconfined situations. Another difference is that the cone of depression will be larger since it only reflects a drop of the hydraulic pressure. Still, if the "artesian well" in figure 2 should be pumped it is important to recognize that some recharge will take place also through the confining bed.

The groundwater table will vary with seasons under a year depending on climate. Most important is the precipitation and under what season the precipitation occurs. Normally, most of the recharge takes place under non growing seasons in the European climate zones.

4. **How aquifer properties are obtained**

By studying topographical, geological and hydrogeological maps and descriptions, data from existing wells and older site investigations a conceptual understanding of the hydro geological conditions can be obtained. The latter ones may contain geophysical data as well as older pumping tests and so forth. Any information on groundwater chemistry is of importance as well as information of the natural groundwater temperature. This is the first step in site investigation, at least for open loop systems. However for these kind of applications a more detailed picture is normally required by the designer.

The next step in the site investigations may include test drillings, geophysical logs and pumping tests with water chemistry analyses in order to fully understand the aquifer conditions.

Except for water chemistry, the most important parameter describing an aquifer is the *permeability* (or *hydraulic conductivity*). This property is defined as the resistance for water to flow in the aquifer material and it is expressed as a flow rate (m/s) when it is affected by the gravity (gradient 1.0), and is main factor for estimation of well capacities at different parts of the aquifer. This and a few other hydraulic properties is most commonly obtained by longer pumping tests. During such a test, the groundwater table is monitored and the drawdown cone around the pumping well is established, see figure 4.

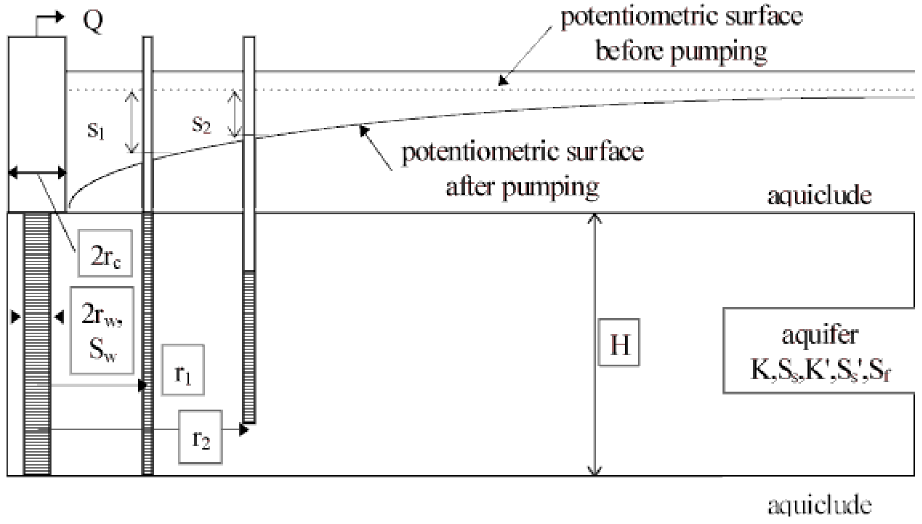

Figure 4. Hydraulic properties of an aquifer is obtained by a longer pumping test where a number of observation wells or pipes is used to determine the shape of the draw down cone.

From the pumping test the permeability is evaluated as *Transmissivity* (m^2/s). This parameter express the added permeability's meter by meter. By dividing the transmissivity with the thickness of the aquifer an average permeability is given between the pumping well and the observation points.

If the test is proceeded till a steady state situation (cone of depression fully developed), the leakage factor as well as the storage coefficient can be determined. These factors are less important but may be critical when it comes to modelling and simulations. Also boundary conditions (positive or negative) may be essential for modelling, especially if they occur close to the well sites.

More information

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Chapter 14

Well types and construction methods

By Olof Andersson

1. Introduction

Open loop systems contain a number of wells normally placed in the same aquifer. The function of these wells could be for production, injection or both production and injection of water.

Independent the wells have a single or double function they have to be constructed properly. If not the system will have serious operational problems and in the worst case be shut down.

By a proper well it has to fulfil the following functional requirements.

- **Allow water to enter, or to be injected, with the lowest flow resistance possible**
- **Produce water without fines coming from the aquifer**
- **Constructed in a way that makes the aquifer being protected from contaminations**

2. Why should drillers care about well construction methods

A drilling contractor must be aware of that the construction of wells for an open loop system is a challenge and may be a complex task considering the requirements sated above. It is likely that the responsibility of the well design and construction will be placed directly on drilling contractor, who presumed by the market to have more experiences then a shallow geothermal designer.

3. Type of wells and construction procedures

3.1 Introduction

There is no pronounced difference between designing and construction of water wells and wells supply and wells used for energy purposes. However for shallow geothermal with open loop systems the wells are used also for injection and also for both extraction and injection.

There are two main type of drilled wells, *open hole completions* and *screened completions.* There is also a third type of well, *the dug well*, This type of wells are has commonly a limited capacity, but is occasionally used for minor GSHP systems on the country. Due to the stable groundwater temperature such a system works with a high efficiency. However, a problem could be the disposal of chilled water, if there is no surface water nearby. Often a

3.2 Open hole completions

The open hole wells, sometimes called a wellbore, is the simplest type of drilled wells. They consist of a casing and a open hole, as illustrated in figure 1, and are typically applied in consolidated formations of different kinds.

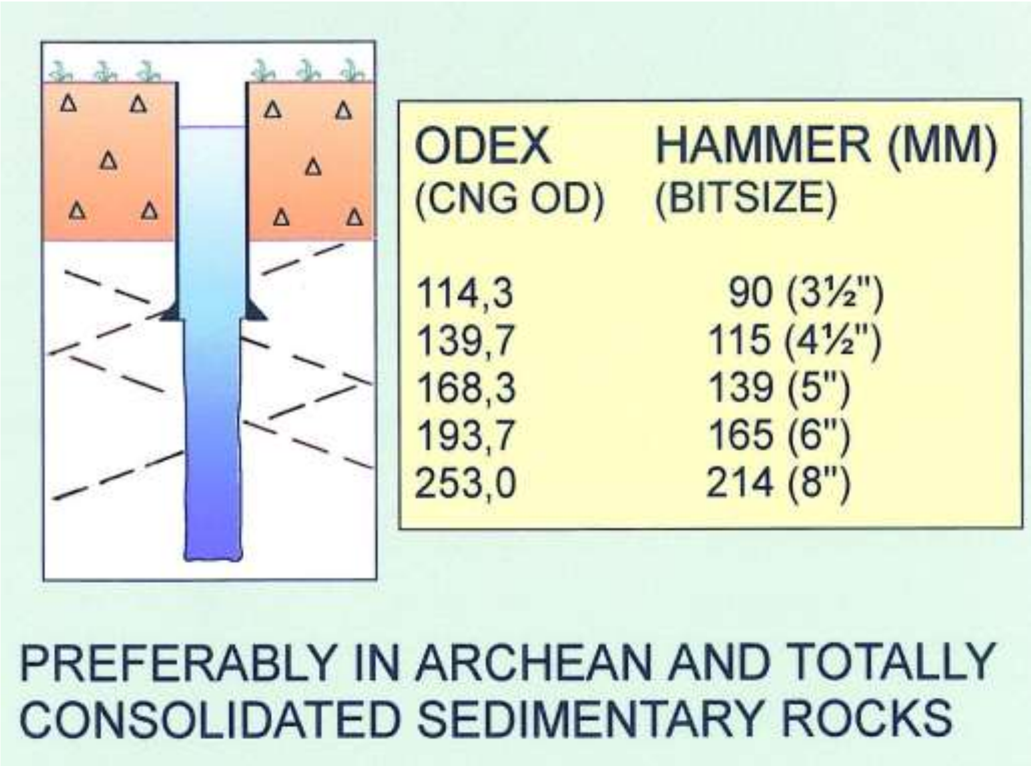


Fig. 3. The open hole completion type of well (the wellbore)

The construction will normally involve four steps. In the first step (1) the casing is drilled down through the overburden and into stable the rock. This is preferably done by using ODEX or TUBEX, but also other hammer drilling methods such as NO-EX and TUBEX can be used as well OD-methods with rotating casing. Occasionally and especially for large dimensions and shallow wells, the casing is driven down by the cable tool method.

In the second step (2) the casing is sealed by grouting. The aim is to protect the groundwater from being contaminated from the surface though the annular space between the casing and the drilled hole. Another function of the grout is to secure tight conditions at injection. When a well is used for injection or recharge of water the injection pressure may be as high as 2-3 bars. The gout should preferably be pumped down to the bottom and forced to the surface by pressure using a packer or a plug. Before the grouting the casing should be pulled a meter or so and then replaced afterwards. By pushing the casing a little bit further down the grout in the annular would be protected while hardening and the drilling of the open hole (3) can start immediately. This is commonly done by DTH drilling but of cause other drilling methods for hard rocks can also be used.

The final step (4) is the cleaning of the borehole that will typically be done by airlifting through the drill rods. It is important that the water is perfectly free of visible particles before ending this part. In some cases and depending of the rock, the hole may be reworked several times to have a proper cleaning result.

3.3 Screened completions

As shown I figure 4 there are two types of screened wells, one being *gravel packed completions* and the other being *formation filter completions*. The latter type of well is also named *"lost filter completion"* since this method use the drilled casing as the production casing of the well. This is the most common design for this type of well.

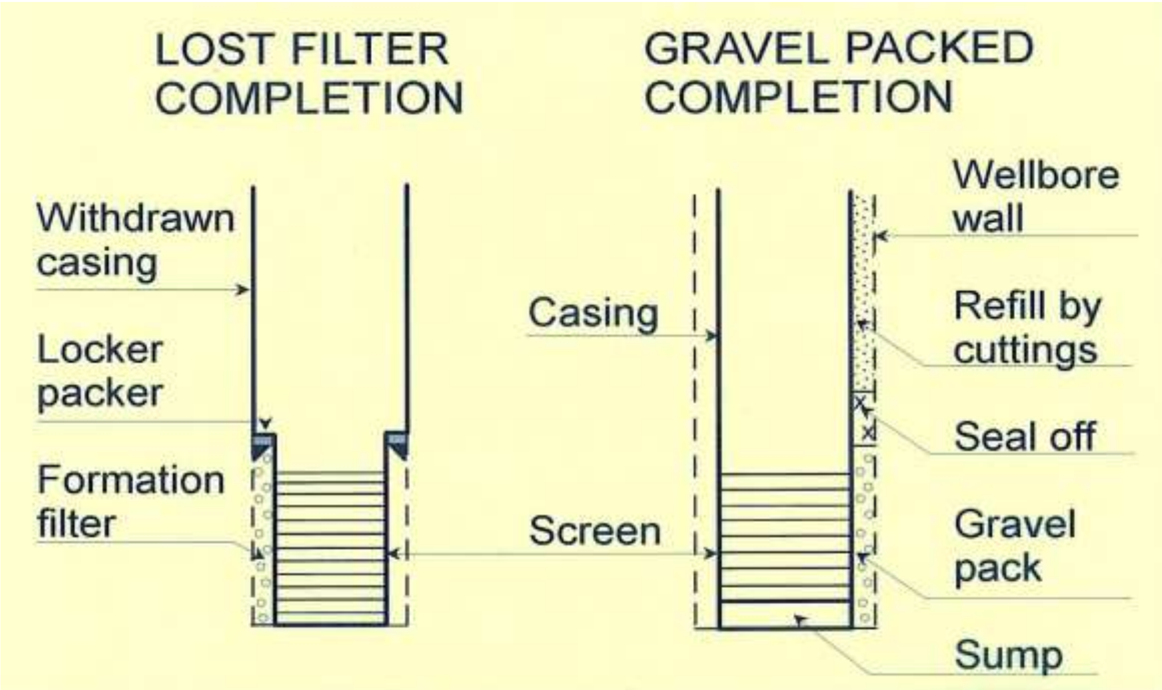
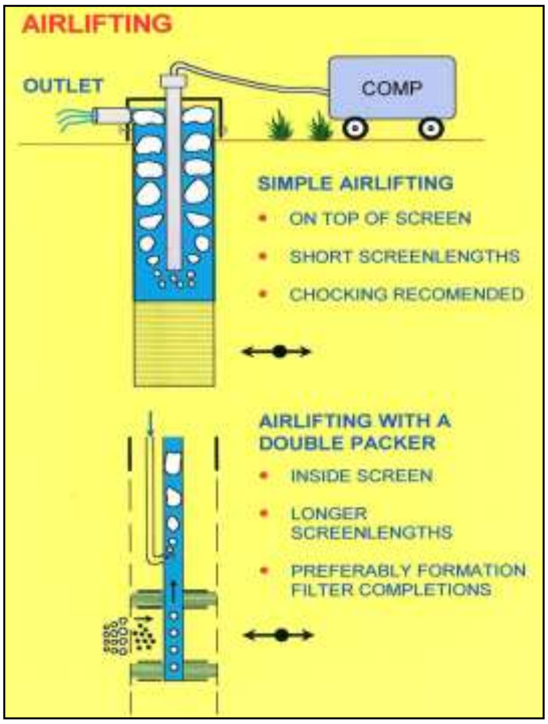


Fig. 4. The two main types of screened wells and their principal design and components

The lost filter completion

A lost filter completion is typically applied for shallow high capacity wells placed in eskers, glaciofluvial deltas and river banks with coarse gravel and sand. The construction is done in four major steps, the first being to drill down the casing (1), preferably to the bottom of the aquifer. This can be done with any casing drilling method earlier named. In the next step (2) the screen, with a packer on top, is lowered to the bottom of the casing. This is normally done by using a wire attached to a hook on the bottom plate of the screen. Having the screen at place the next step (3) will be to pull back the casing up to top of the screen to have the packer resting on the shoulder of the casing shoe, making a tight connection (see also figure 7, further down). Finally (4), the well is developed by air lifting or hydraulic jetting. The main purpose with the development is to wash out fines around the screen and to have an accumulation of coarse particles around the screen as illustrated in figure 5. The development should be carried out with high forces and continue till the produced water is perfectly free of particles.



Easy and practical to arrange if the well has been drilled with air
The most common method for lost filter completions,
Works best with an "on and of" procedure that will help getting particles moving

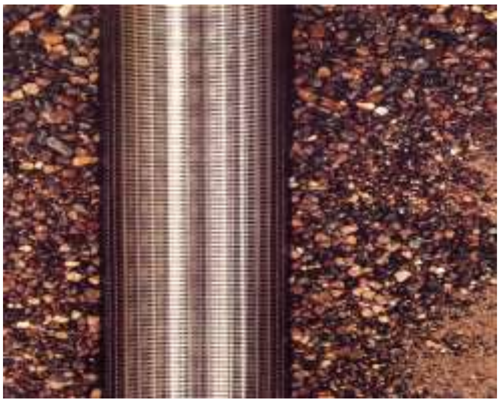


Fig. 5. Air lifting is the most common way for development of formation filter completions

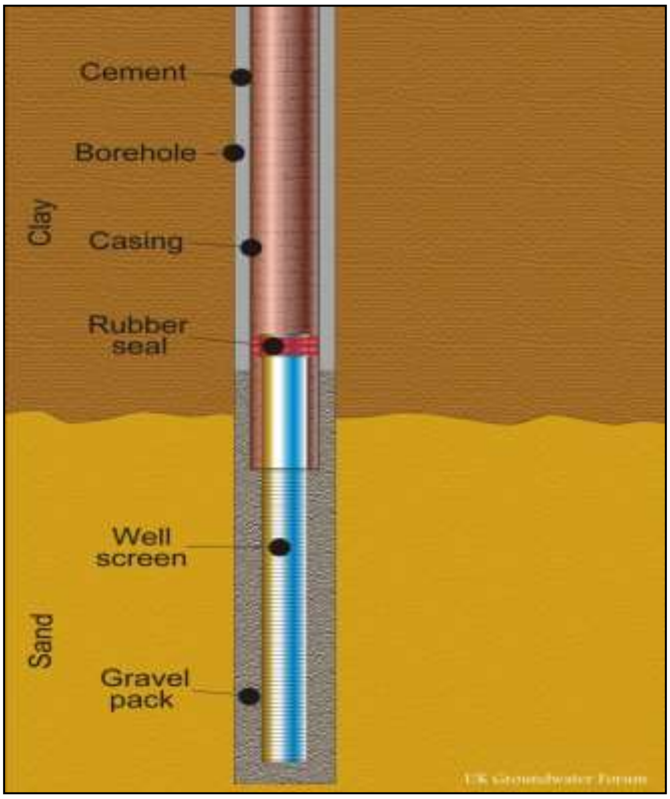
To obtain a good development result by air lifting, a double packer may be used for longer screen lengths (> 6 m as a role of thumb). This will concentrate the washing force to sections of the screen and is therefore more effective.

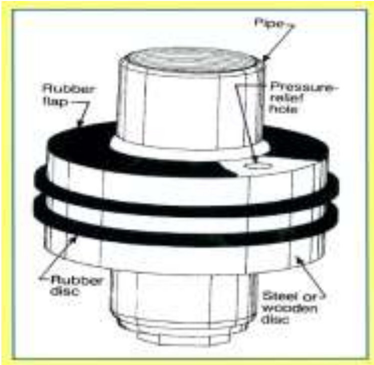
Another common cleaning method for development is by hydro jetting. In this case a jetting tool is with nozzles is placed on the drill rod and rotated inside the screen. For this method a high pressure is needed in order to have jets that penetrate the slots of the screen and disturb the grains outside. This method will be more efficient if the well is also pumped during the development.

The gravel packed completion

The gravel packed types of wells are commonly applied for deeper aquifers in delta sediments and unconsolidated sandstones. The drilling methods may vary, but the dominating method would be rotary with straight or reversed circulation of the fluid.

A typical configuration of such a well is shown in figure 6. The construction is would normally encounter a number of steps normally being (1) drilling down a temporary conductor casing or a standpipe, (2) drill an open hole with water or mud, (3) lowering the screen and production casing with centralizers into the hole, (4) place the gravel pack preferably by pumping it down through a pipe, (5) pump the well for the gravel to be packed packing and measure the top of pack, (6) sealing the gravel pack by placing swelling clay or grout on top of the gravel, (7) backfilling the rest of the annulus, often with cuttings, (8) cleaning the well by a proper method such as over-pumping or on-of pumping with a submersible pump, and finally (9) if so required, further development preferably by surging. However, other methods may also be used such as hydro jetting, air lifting and swabbing.





Preferably used in well sorted fine grained sediments all over the world (delta sediments or unconsolidated sandstones)

The gravel pack acts as a filter for fines, but are sensitive for clogging by fine grained particles

For development or cleaning surging is a practical option

Fig.6. Example of a gravel packed well. On top left a surge block commonly used for development.

Compared to formation filter completions a gravel pack completion must be more gently developed in order not to have the gravel pack mixed with finer particles from the aquifer formation. If so happens, the well capacity will decrease, sometimes drastically.

4. Guidance for design of screened wells

4.1 Selection of screen type

The technical function of the screen should be (1) to let the water through the screen with a minimum of friction losses, (2) to prevent fines to enter the well, and (3) to allow for development or maintenance treatment. It should also be (4) resistant to corrosion

To fulfil these criteria a screen should have (1) a high entrance area, (2) openings that prevent particles to enter or clog the openings (3) openings that allow mechanical treatment to work outside the screen, and (4) made of corrosion resistant material with respect to the water chemistry.

There are several types of screens on the water well market of which the most common ones is shown in figure 7. It is obvious that the continuous slotted type has the best fit to the criteria stated above, while all other types have less open area or obstacles that increase the friction losses.

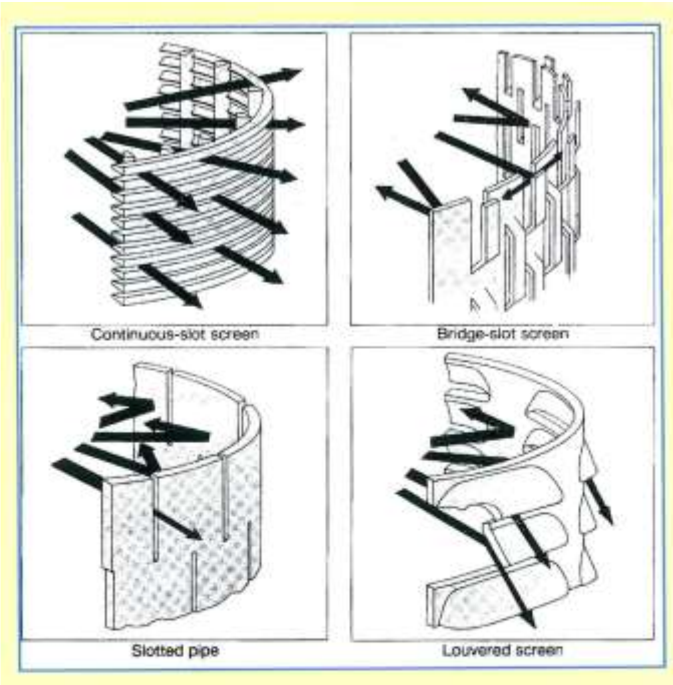


Photo showing a continuous slotted screen together with a simple type of packer used for lost filter completions

Fig.7. Different types of screens with arrows showing development efficiencies.

Most of the screens can be made in corrosion resistant material with stainless steel as a standard. Slotted screens however, is commonly made in plastic, the often to be used in slimmer test wells and observation wells.

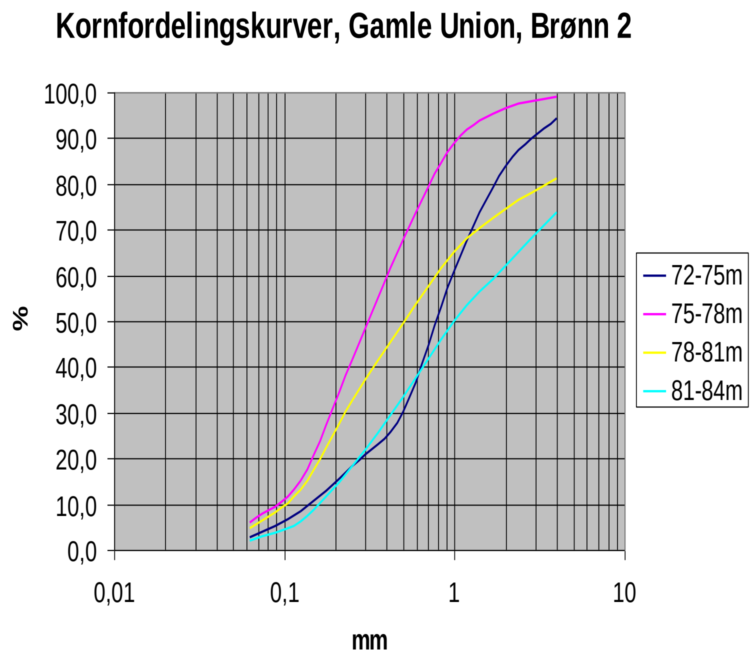
An important factor selecting the screen is the well depth. Screens placed in unconsolidated formations must have a compressive strength that relates to the horizontal soil pressure. For this reason screens made of plastic will only be applicable at more shallow depths.

4.2 Selection of slot size for formation filter

Basis for design this type of well is grain size analyses. It is therefore essential that accurate samples are taken prior to the design.

To design a natural developed formation filter around the screen the grain size distribution curves are used. Referring to the example in figure 8, the first step is to define the uniformity coefficient (Uc) by dividing the grain size where 60 % of the sample is passing the sieves (d60), with the size where 10 % is passing (d10). In the example the Uc-value would be 4, 0 that fulfill the first criteria for that states a Uc-value of >2, 5.

The next step in the designing procedure would be to decide the slot size of the screen. Bearing in mind that the goal is to wash out as much fine grained material as possible and to build up a section of course grained material around the screen, this selection is of great importance. If the size is to large, the well might end up as a sand producer. IF its to narrow the efficiency may not be as high as expected, or the slots could be clogged by fines during the development.



Main criteria

Unconformity (D60/D10) should be > 2,5

The layer with the finest grained fraction should be basis for the design (violet curve)

Slot size of the screen should be selected so that some 50-60 % of the material can be cleaned out (red line)

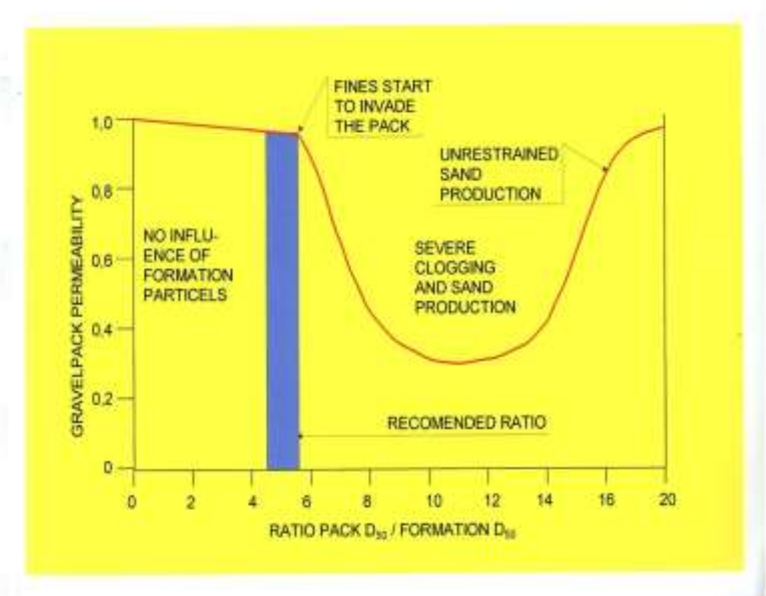
Fig.8 Grain size distribution curves are used to select the slot size of the screen.

Except for the criteria stated above and in the figure, a layer with fine grained material must be overlaid by a layer with courser within the screen length. The finer layer will in this case be washed out and replaced by courser grains close to the screen.

The example in the figure suggests a slot size of 0, 3 mm. However that is not a standard size. In such cases the closest standard dimension should be selected, in this case 0, 25 mm. Other standard sizes are 0, 5, 0,75, 1,0 and 1,5 and 2, 0 mm.

4.3 Selection of single graded gravel packs

In a gravel packed well the space between the borehole wall and the screen is filled up with a grain size that is much more permeable than the formation in which the well is placed. The function of the gravel pack would in principle be to prevent fine grained particles to enter the well, but on the other hand let water through the pack with a minimum of flow resistance. To achieve this function the diameter ratio between the grain size of the pack and the grain size of the formation sand should be in the order of 4,5-5,5. This is a theoretical ratio based on the fact that the pores of the pack will not let formation sand pass into the pack unless the ratio becomes bigger than 5,5. This is illustrated in figure 9 that also suggest that ratios in the order of 8-12 will cause severe clogging and sand production problems. It also shows that a ratio in the order of 16-29 will have an unrestrained sand production. This type of pack is only applicable as a borehole wall supporting filter to prevent pieces of rocks to enter a well.



Main criteria

Unconformity (D60/D10) should be < 2,5

The finest grained layer in the aquifer should be basis for design

The gravel pack should have grain size d50 < 5 times the d50 value of the formation sand (preferably within the blue column in the figure)

Fig. 9 The optimal ratio between the gravel pack and the formation sand

Based on grain size distribution curves, gravel packed wells is used if the Uc-value is < 2, 5, but could of cause also be used for less sorted formations if for any reason the natural developed formation filter is not applicable. The second criterion is that the sample with the finest grains should be used for sizing the gravel pack.

It is better to select a somewhat smaller grain size for the pack than the theoretical value. Even if this will decrease the permeability to a minor extent, the great advantage is that the risk for clogging and sand production will be minimized. Common standard gravel packs are sized in d50-values from 0, 8 and upwards. The grains in 0, 8 mm pack will vary between approx. 0, 6 - 1, 0 mm.

The gravel pack material should preferably be well sorted in a single fraction and consist of round or sub angular quarts sand. The slot size of the screen should be at least 0, 2 mm smaller than the finest grains of the pack.

In figure 10 an example is given on how a single graded gravel pack is designed. In this case, a typical delta deposit, there are a number of well sorted beds of medium sand (B) and medium.-fine graded sand (A). All beds are well sorted and the sieve analyses suggest a Uc-value around 2,0. The finest bed will be the basis for design with a D50-value of 0,18 mm. The gravel pack selection would in this case be 4,5 times that value, ending up at a D50 of 0,8 mm. A proper size of a standard gravel would in this case be 0,6-1,2 mm. The maximum slot size on the screen is by the bock 0,4 mm, but in this case a standard size of 0,25 mm is the best choice. If 0,5 mm is chosen, there is a risk that the finest grained particles of the pack will clog the screen.

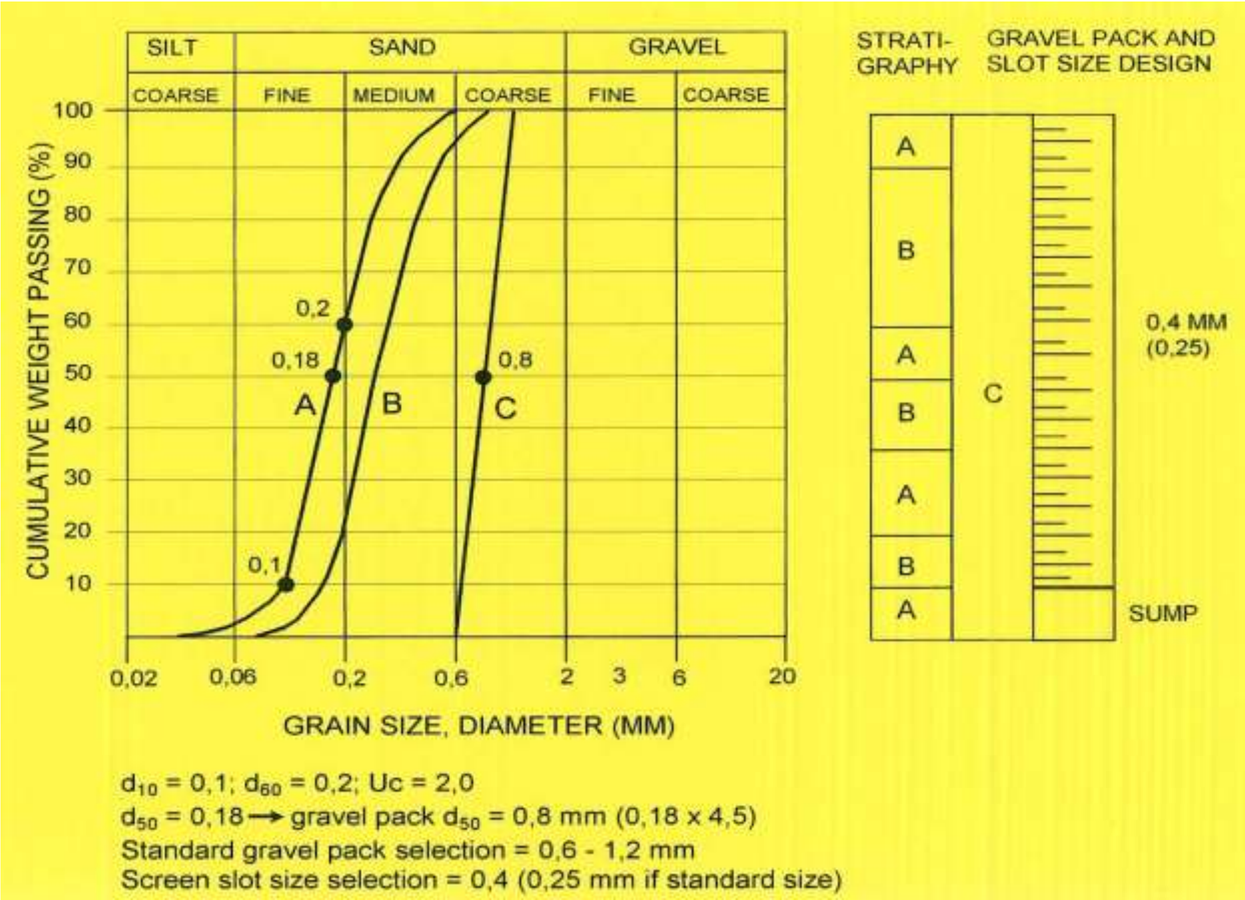


Fig.10. Example on how to select the gravel pack (C) and screen based on the grain size distribution of finest grained layer (A).

4.4 Multiple graded gravel packs

The principle for multiple graded gravel packs and screen slots is to adept the well design to the complexity of the aquifer strata. In such a design it is of uttermost importance to determine the precise levels, thickness and fraction of each stratum. This will of cause be a challenge when it comes to test drillings and how the samples then are taken. It will most probably also involve geophysical logging, such as caliper, electric and gamma logs.

The design is based on having different gravel packs for different stratum through the aquifer layers. The objective is to fully use the permeability also when it comes to less productive zones. This is a very challenging type of well to design and even worse to construct. It is therefore recommended to only use the most productive zones with a single graded pack and to use blank sections passing through less productive layers.

5. Well type selection

In order to select a proper well type it is essential to have a accurate knowledge of not only the capacity demand, but even more important, a clear picture of geological and hydro geological conditions at site.

Based on results from existing knowledge (geological maps, well archives and such) and test drillings, the first step in any well design would be to combine that knowledge with optional alternatives as shown in figure 11.

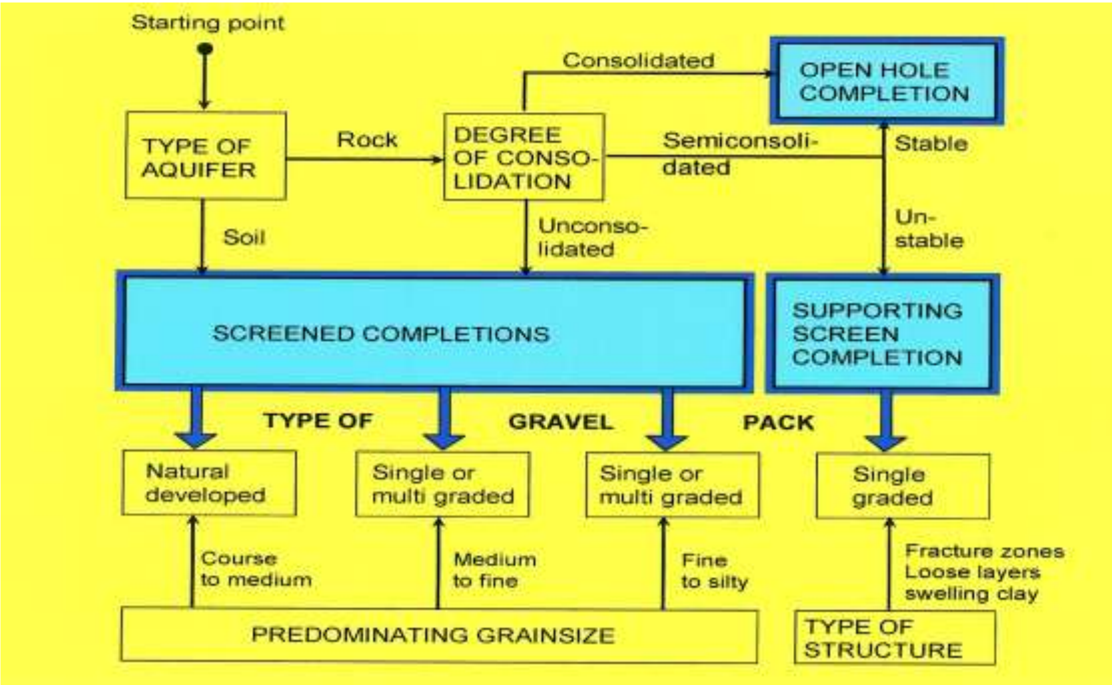


Fig. 11 Flow chart for selection of well type based on geological conditions

The flow chart indicates that that the degree of consolidation is the main factor for selection. If the formation is consolidated enough to maintain the stability during drilling and pumping of water, there is no need for screens. In this case an open hole completion would be the simplest and cheapest well type to select.

If the borehole is predicted to be partly unstable due to fracture zones or other tectonic structures in a hard rock, the flow chart suggest a supporting screen completion. This may consist of a slotted liner that could be a steel casing or a slotted plastic pipe around which a coarse filter material is packed.

The trickiest situation is to design and construct gravel packed wells in formations that is dominated by fine sand. These types of aquifers constitute the very edge of what is possible for well applications. For grain sizes dominated by medium sand a single (or multiple graded) gravel pack solution is the only alternatives. In aquifers with coarse and medium sand the natural developed formation filter would in most cases be chosen. However, the criterion of an Uc-value > 2, 5 decides if this is possible. If not a gravel pack solution must be used.

6.0 Tests after well completion

As shown below, there are several reasons for a driller to test the outcome of the well construction after development.

- The well efficiency may not be as good as required
- If not, a second treatment may be necessary to perform
- The actual specific capacity (not the designed) is basis for selection and setting depth of the pump
- The actual value of the hydraulic conductivity (not the predicted) will be used for model simulations
- Undisturbed water samples must be taken to check the chemistry and the physical properties
- From a contractual point of view, the result will be used to check if the requirements according to the contract is fulfilled

Any screened well will have a certain inflow resistance through the screen. This is expressed as a well efficiency and is defined by the ratio between the draw down in aquifer compared to the drawdown inside the well. This resistance will increase if the well screen gets clogged by particles or if the well has not been properly developed. Normally the natural developed wells have a higher efficiency than gravel packed wells. The reason for this is often that fines from aquifer is accumulated toward the pack and forms a skin that is less permeable. Common efficiency factor values would be 0.85 -0, 97 fore natural developed wells and 0,60- 0, 80 for newly constructed wells. These figures mean that from 3 up to 40 % of the draw down is due to friction losses when the water enters the well.

In figure 12 an example of a step draw down test is given, in this case a well with a natural developed formation filter.

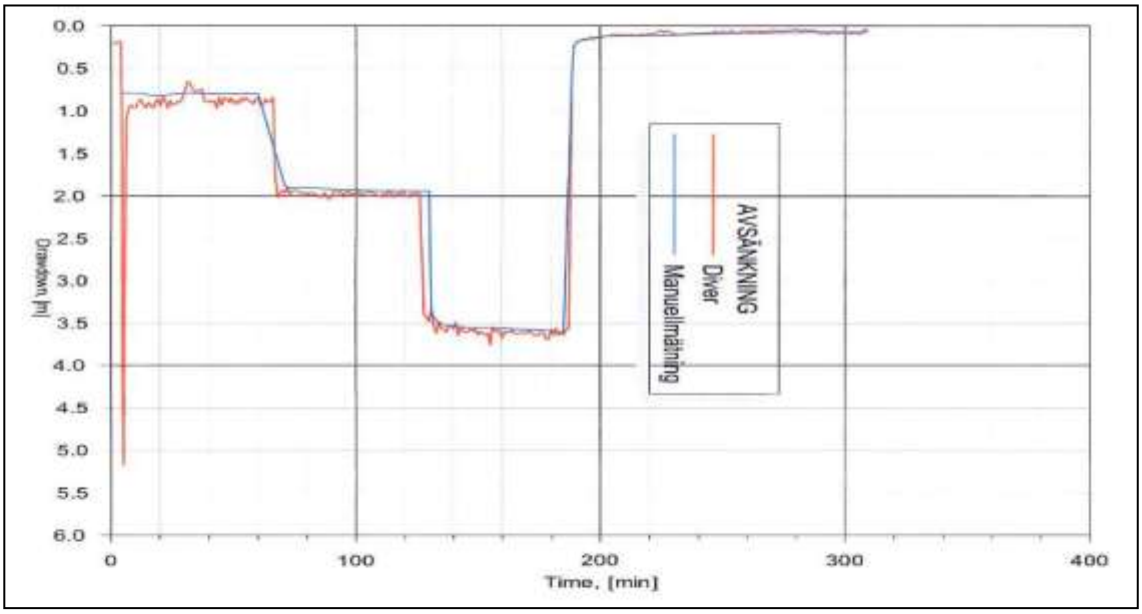


Fig.12. Example of step draw down test to determine the efficiency of a well.

The figure shows the draw down each step and by evaluating the specific capacity each step; the efficiency can be simply calculated. By specific capacity means the flow rate (Q) divided by the draw down (s). If Q/s is equal each step the efficiency is high. If it drops with an increased flow rate its lower.

Commonly the drilling contractor is executing these kinds of short tests and hands over the measured value to the customer for his evaluation. For this reason it is of importance for the drilling contractor to know the procedures for such pumping tests and how to do the measurements in an excepted way. This procedure may be described by the following list.

1. Install a submersible pump in the well with a riser pipe and a disposal pipe. Make sure that the pump is not too high up in the well, causing it to suddenly suck in air. Also make sure that the pump is large enough to produce the expected flow rate.

2. Arrange for electrical supply to the pump and place a flow meter and a valve on the disposal pipe. Check that the out let is placed so it will not disturb the environment and that it not will influence the test it self.

3. If a submersible pressure devisor (diver) is used for logging the draw dawn, install this together with the pump in stage 1. Make sure it is programmed for tight recordings. Even if a diver is used, manual readings, preferably with a electrical sounder, must be carried out through the test as back up measurements.

4. Make a first quick test for about 10-15 minutes to check that everything functions. At that test also measure the draw down and learn how to use the valve for adjustment of different flow rates.

5. Let the well rest for at least the same time as the short check test. Then do the reference measurement in the well and perhaps also in nearby other wells.

6. Start the pump and perform manual measurements with as short intervals as possible the first 10 minutes, the gradually with longer intervals before the shut off (after approx. 2 hours for single flow tests). Also note the flow rate at least every 10 minutes.

7. If a step draw down test is asked for, use 30-45 minutes each step, and repeat measurements with short intervals at the beginning of each step. The flow rate increase should be adjusted by the valve with a known opening turns in advance, learned from step 4.

8. Before stopping the pump, a water sample should be taken at the outlet. In some cases more than sample is asked for. At water sampling the temperature should be recorded by a thermometer (there is also a inbuilt thermometer in most divers).

9. Finally, if required, also the recovery shall be measured manually and by the diver. The manual measurement should be executed with short intervals to start with.

10. Lift the pump and recover the diver. All obtained data and water samples shall then be handed over to the customer as soon as practical for his evaluation.

The drilling contractor is sometimes asked to conduct also longer pumping tests. In such a case the same procedures should in principle be followed when it comes to practical preparations. However, the measurements are then often carried out by as a third part service of somebody else. These tests involves measurements in a number of observation wells or pipes, registration of water levels in lakes, climatic parameters, etcetera, and may continue for several weeks or even months.

7.0 Additional guidance

It should be recognized that the well technology has a poor status when it comes to research and education. The knowledge and experiences are basically held by the water well drillers them self and will of cause differ between countries and regions, just like drilling methods.

In addition to what is earlier written in this chapter, some additional recommendations concerning screened wells are as follows.

- Do never use bentonite as an additive to drilling fluid since it may clog the pores permanently. Use instead polymers (CMC) that are self destroyable.
- Preferably use continues slotted ones, that have proven to be more efficient, less sensitive for clogging and that makes the well more easy to maintain will mechanical treatment methods.
- For gravel packed wells, always use centralizers, in order to have the well string in the center of well. If not, the gravel may be difficult to place and the risk for sand production will increase.
- To avoid sorting, contamination and bridging placing the gravel pack by gravity dropping the best performance would be to pump it down through a tremie pipe, starting to fill the gravel at the bottom.
- The calculated thickness of the gravel pack should be at least 50 mm and reach well above the screen top (at least 20 % of the screen length).
- Be careful not to let air out in aquifer during well development with air lifting. Entrance of air will effectively clog the permeability and is hard to flush back again.

More information

Fletcher G. Driscoll, 2008. Groundwater and wells, Third edition. *Johnson Screens ltd, St Paul Minnesota.*

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Chapter 15

Well installations and over-structures

By Olof Andersson

1. Introduction

An open loop system will create a separate circuit from which heat and or cold is transferred to other circuits through heat exchangers. The thermal function of the ground water circuit is highly dependent on the state and development of the wells from where the water is pumped and to which it is returned.

Independent the wells have a single or double function they have to be properly equipped to be functional. Furthermore, monitoring of the performance is important since devices make it easier to trace potential well problems. The parameters that should be continuously, or at least momentarily measured, inside or at the wells are the following

- Draw down as a function of flow rate
- Injection pressure as a function of flow rate
- Flow rates each well
- Temperatures in and out of borehole

It is also advisable to have the mains in groundwater circuit monitored by pressure, flow rate and temperature if the system contains a number of wells.

2. Why should drillers care about well installations

A drilling contractor may not be responsible for designing the monitoring system, but will in many cases install the devices as a part of the contract. Apart from that, the driller will always be more or less responsible for the well behaviour also after construction. It may even be that the drilling contractor will have a maintenance contract for the wells he constructed.

3. Well installations

3.1 Pump selection

Submersible pumps are used to run the circuit in which the groundwater is circulated. A pump should be designed by flow rate and static head. The static head is the sum of the following parameters.

- Friction losses in the pipe system at full flow rate
- The lifting length at maximum draw down, and
- The injection pressure at the recharge

The motor of the pump gives the power to handle the flow resistance and the number of impellers helps to create the volume of flow. The electric motor will normally have the same speed all the time, but in later years it has become common to add frequency control in order to adapt the flow rate to the momentary demand. In figure 1 a submersible pump is shown together with equipment for frequency control that will save a substantial amount of electricity.

- **The pump should be placed well below predicted maximum draw down**
- **IN screened wells, never put the pump in a well sump (the motor is chilled by water passing the cover)**
- **Frequency control will save electricity and be favourable for the control system**

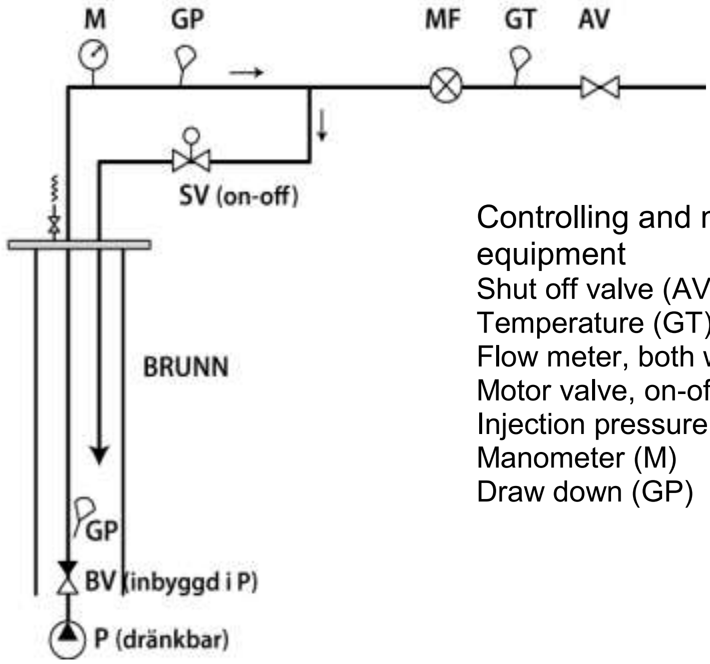
Fig.1 Submersible pump with motor and impeller and the intake of water placed between. The next image shows a box for frequency control (left) and a box for electrical connections for the pump and controlling devices in and close to the well (right).

Chapter 15

4. Controlling and monitoring devices

To control the flow direction and to keep a track on the behaviour and functional behaviour of wells used in open loop systems, it is of great importance to monitor the flow rate, temperature and the draw down and/or the injection resistance. In this way problems related to clogging of wells can be early traced and possibly cured.

The common practice, at least in larger systems, is to install devices for logging flow rates, temperature and pressure. An example of such an installation is shown in figure 2, in this case for a well that is used for both extraction and injection of groundwater. Such a well has a submersible pump with an inbuilt back valve and an injection pipe for recharge. This is closed at extraction and open at injection. These types of wells are common for ATES systems that work with two directional flows.



Controlling and monitoring equipment
Shut off valve (AV)
Temperature (GT)
Flow meter, both ways (MF)
Motor valve, on-off (SV)
Injection pressure (GP)
Manometer (M)
Draw down (GP)

Fig. 2. Example of controlling and monitoring devices for wells used for both extraction and injection

In the best of situations, all parameters are continuously logged and plotting's. This way the function of the system can be followed and the controlling program be corrected if required.

It is important that the well top is air tight. Most often a flanged lid is used, but expansion lids may be an option. Return pipes in wells used for both production and injection may be double due to a limited space in the casing as can bee seen in figure 3.

For most applications stainless steel is used for piping. However, using plastic piping is much cheaper and simpler, and corrosion resistant

Expansion well top with three openings for tight connections

A typical injection well with a safety valve disposal

Fig 3. Examples on top piping of wells used for double function (left) and recharge only (right)

In at least Scandinavian countries it is common that the drilling contractor makes the installations in at the well, the piping system, valves and meters included. However ever in such cases the devisors are preferably delivered by the contractor responsible for the controlling equipment.

5. Well over-structures (well houses)

All wells need some type of protection from different weather conditions, thefts and vandalism. There are two main solutions for that these well house, (1) placed on the ground and (2) under surface, the latter often called a well cellar. Examples on common constructions are shown in figure 4.

Fig 4. Drillers are occasionally responsible for delivering the well houses. Here examples of house placed on the ground and one simpler dug down beneath the surface.

Ever way, the requirements of any proper well house or cellar should as follows..

- Space enough to carry out the construction work and the upcoming maintenance work
- Safe to enter considering the risks to get injured by falling or slipping, and even worse, that poisoning gas may be accumulated.
- Dry and ventilated inside in order to prevent the equipment from corrosion problems or being damaged by moisture or water.
- Not easy to unlock to prevent from thefts and vandalism

These criteria would be easiest to achieve for well houses on the ground. For different reasons this not always possible and often the well heads have to placed under the surface with a limited space to work and with a high humidity, and sometimes water. In figure 5 a couple of good practice examples is shown together with a less functional under earth cellar.

Fig. 5. Two examples of ground standing well houses, and one tight and less functional below surface.

Based on the requirements and long term conditions inside the well house or cellar, it is strongly recommended to preferably use an insulated structure that stands on a drained ground, or a plate of concrete. The house should be able to easily lift or fold to make it easy to lift the pump and and make other forms of maintenance work. It should be ventilated and have a minor radiator to keep a law humidity inside. The ventilation is also important to keep the temperature down during summer when solar radiation will make the temperature to raise to high levels.

In the case cellars must be used for ethical or space reasons, preferably water tight bottoms and tops should be used. Furthermore, a permanent ladder should be installed as well as light and a heat radiator. If possible, some kind of ventilation should be considered.

Chapter 16

Well problems and maintenance

By Olof Andersson

1. Introduction

Open loop systems are in general more sensitive for operational problems compared to closed loop systems. It may even be challenge to have an aquifer system to work properly. The potential risks are illustrated in figure 1.

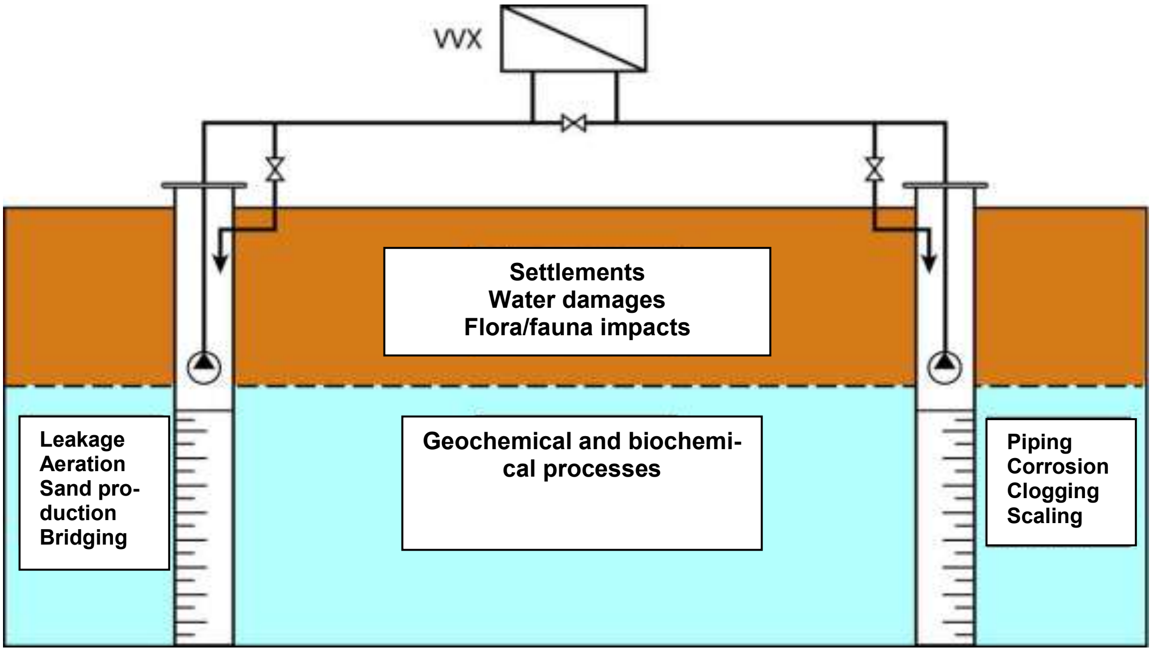


Fig. 1. Potential technical and environmental problems related to open loop systems

As can be seen in the figure, most problems are in fact based on (1) the influence of the draw down and up lift cones, (2) the quality of well design and construction, and (3) the chemical characteristics of the groundwater.

Failures or problems may be prevented by using restricted flow rates, a proper well design, a system design that minimise scaling and corrosion, and of cause a maintenance program that allow measures to be taken in an early stage. However, under certain unfavourable conditions an open loop system should never be an option. In these cases it is better to chose a closed loop system.

2. Why should drillers and installers care about problems and maintenance

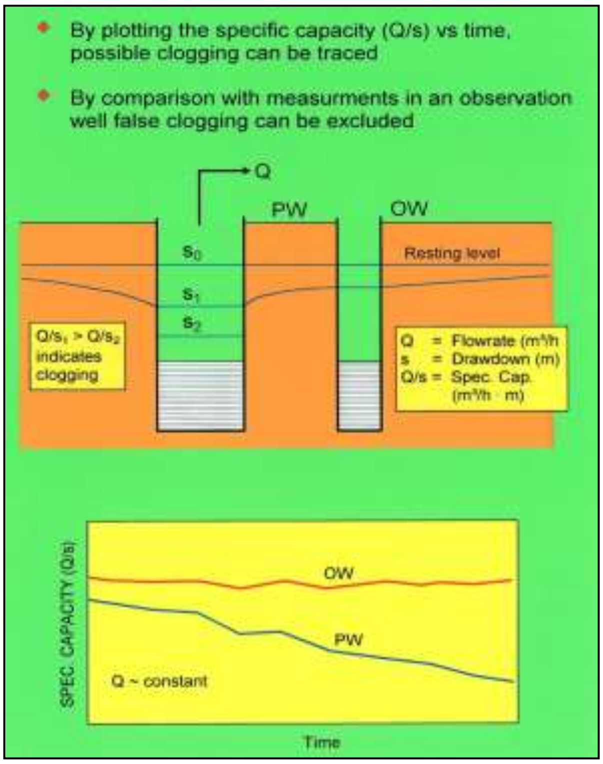
It is essential a driller or a drilling company to be aware of the processes and circumstances that lead to well problems or total failures. By having that knowledge these potential problems can be minimized and by a careful well design, construction and development. The understanding of failures will also be of help at forming maintenance programs, the elongated issue and responsibility for well constructors

3. Problems related to clogging

3.1 How to trace clogging

The most common technical problem is clogging of wells. Clogging is defined as an increased flow resistance for water to enter the well (or be disposed through the well). The clogging process normally gets more and more evident with time and will result in a lower and lower well capacity.

Clogging can easily be traced and dealt with in an early stage by monitoring flow rates and drawdown as shown in figure 2.



Clogging is defined as an "increased resistance for the water to enter the well", and it will result in:

A decreased flow rate with time

An increased draw down in the pumping well, combined with

A long-term steady levels in observation wells
Detection of clogging requires monitoring over a long period of time time

Fig. 2. *By using a monitoring program clogging can easily be traced in an early stage. On top right, a clogged inlet screen on a submersible pump, cased by iron precipitation.*

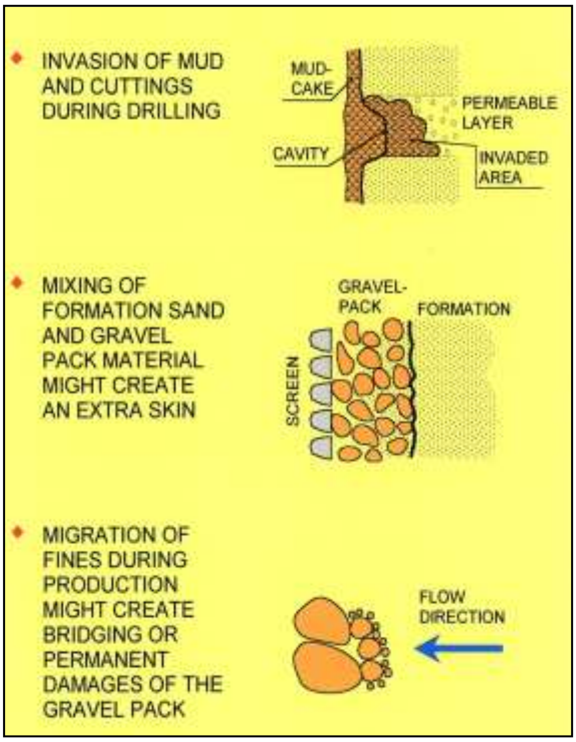
The figure illustrates how clogging can be traced by plotting data from an observation well (OW) and compare that to the production well (PW). In this case the production well shows a decreased specific capacity while the observation well shows a steady level versus time. The only explanation is then that the resistance for water to enter the production well is increasing. The increased resistance will lower the drawdown inside the well, while the groundwater table outside the well is kept constant. This will increase the hydraulic gradient (the driving force) between the well and the aquifer and hence maintain the capacity of the well to start with. Later on, with more clogging, also the capacity will drop.

"False clogging" sometimes occurs. Such events are either explained by a general lowering of the groundwater table or by failure of the submersible pumps cutting down the flow rate. However, by ground water level in both the production wells and the observation wells or pipes. If so happens such events can be excluded as a result of clogging.

Another false clogging of the well itself is if the inlet of the submersible pump is getting clogged, that sometimes happens due to iron precipitation, see figure 2. In such cases, the flow rate will decrease, but on the other hand the drawdown will also decrease showing that it is only the pump that is clogged.

<u>3.2 Clogging cased by particles</u>

Already during drilling and well construction there are certain risks for clogging of the aquifer porosity. As illustrated in figure 3, fines may invade into permeable beds and decrease the yield capacity. A well known such clogging additive to the drilling fluid is bentonite. If bentonite is invaded and gelled in the porosity it is very difficult to clean out. For this reason it is much better to use polymers that will break down by it self.



Main causes for particle clogging

Invasion of unbreakable mud into the porosity

Migration of fines towards gravel packs

Bridging in general

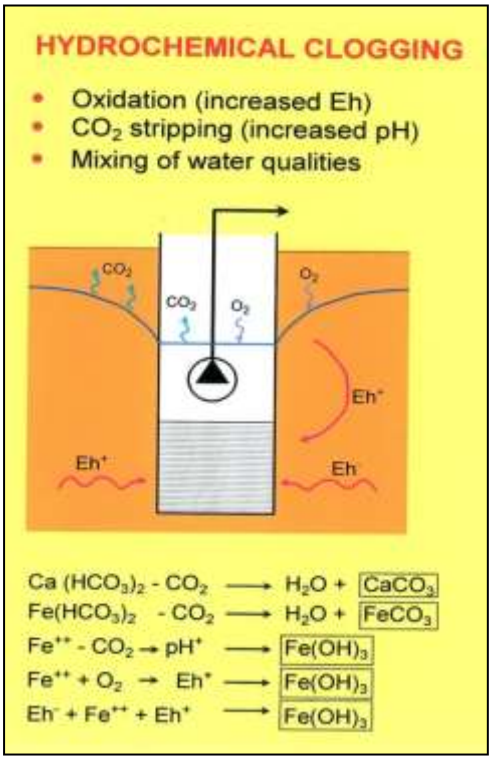
Fig, 3. The main reasons for clogging by fines or solid particles. Down right, an example of a totally clogged well screen.

During the construction of gravel packed wells a critical stage is the placement of the gravel pack. This procedure should be carried out in a way that the gravel is not mixed with formation sand. For this reason its better to pump down the gravel through a tremie pipe rather than to drop it down and let it sink by gravity forces.

Even if a well has been properly designed and constructed, there is always a certain risk for a gradually clogging process cased by migration of fine grained formation particles. Typically, these fine particles will form bridges in the well vicinity which will increase the flow resistance. However, these bridges can be broken down by a reversed flow and the fines may be flushed to the surface by a further well development. For this reason wells with potential bridging should be constructed so they easily can be flushed.

3.3 Hydro-chemically caused clogging

Under certain conditions the wells may be clogged by solid chemical precipitates. Most common of these are iron, manganese and calcium composites. The main chemical processes behind these types of clogging are illustrated in figure 4.



Main products of chemically induced clogging

Iron hydroxide
Calcium carbonate
Siderite

Fig.2. Hydro-chemical well clogging processes. At the lower right, iron hydroxide on a withdrawn pump

In general the processes are initiated by changes of pH and the redox potential (Eh) of the water.

Precipitation of carbonates, often referred to as *scaling*, may take place if carbon dioxide is allowed to be stripped out from the water. This happens if the draw down in the well exceeds the bubble point for CO2. For this reason large draw downs should be avoided for water types that are scaling sensitive..

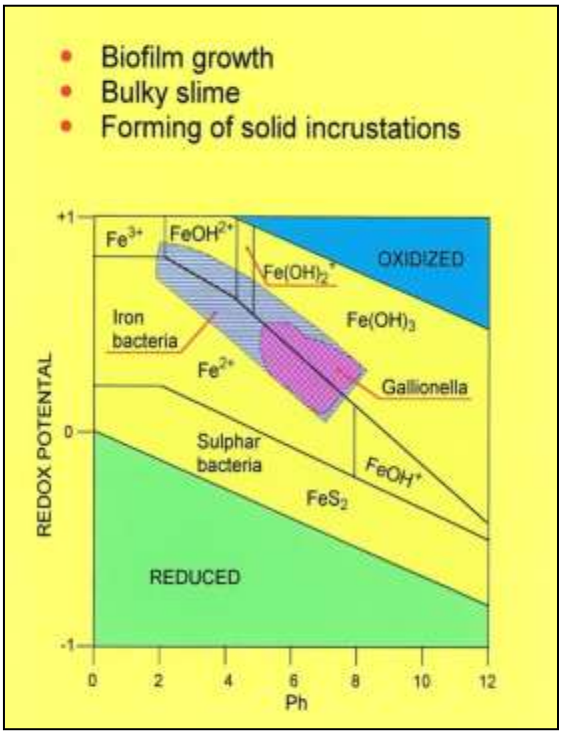
Stripping of CO2 will often cause iron to precipitate, normally as iron hydroxide. A similar precipitation will occur if a reduced type of water is entering the well from one side and an oxidized type from the other side. A third iron oxidation process will take place if reduced water gets in contact with oxygen.

Clogging by iron is by far the most common one. Occasionally, iron is mixed or even replaced by manganese oxides forming a soft and sticky black layer on the screen. In waters that are close to be oversaturated of carbonates and with iron in solution, the wells are sometimes clogged by siderite. This is the worst form of clogging since siderite is almost impossible to remove.

For prevention of hydro-chemical clogging the methods are two measures being (1) design the system in a way that entrance of air to the ground water loop is prohibited, (2) place wells so mixing of different water types is avoided, and (3) operate the wells with a restricted draw down. .

<u>3.4 Biochemically caused clogging</u>

One may believe that groundwater is sterile and free of bacteria of any kinds. On the contrary, a drop of ground water contains hundred thousands of bacteria with different species. The one that frequently makes clogging to occur is the iron bacteria, *Gallionella,* see figure 5.



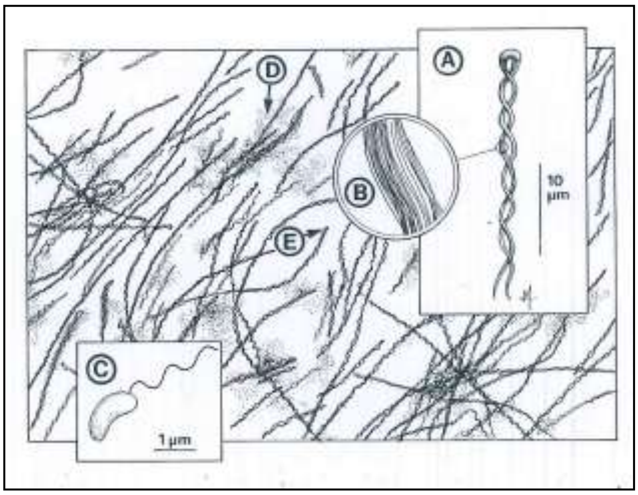


Fig.3. Stability diagram for iron, showing the active area for iron bacteria, of which Gallionella is one.

As indicated in the stability diagram for iron, the iron bacteria are active in water chemical environments that allow the bacteria to oxidise iron in solution into solid oxides. In that process and under certain conditions a bulky slime will be formed that drastically and rather quickly clogs any well screen. However, normally the bacteria form incrustations or a biofilms on the surfaces of the well components.

In figure 5, the active area for sulphur bacteria is also shown. They live in a more acid and reduced chemical environment. Together with iron in solution they will typically be responsible for forming solids like pyrite (FeS_2). The precipitations of sulphur bacteria are recognised as light-dark grey soft biofilm that sometimes will cause minor well clogging problems.

4. Clogging prevention and treatment methods

4.1 Measures for clogging prevention

In order to prevent, or at least to minimise, that clogging of wells occur, there are some fundamental measures to recommend.

- Wells should be designed, based on representative sampling and other geo documentation obtained by test drillings
- The drilling and flushing method should be applied that minimise the disturbance of permeable layers in which the well screen are placed
- At the completion of wells, the screens and gravel packs should be carefully placed and the development should proceed till the back flushed water is perfectly clean
- At the operational mode, a proper pumping schedule should be applied in order not to have the wells working above its capacities or designed flow rates.
- Wells should be equipped with devises that allow monitoring of well behaviour over time, to detect potential clogging in an early stage.

4.2 Well stimulation methods

Wells may lose their original capacity most commonly due to clogging. There are a variety of methods to clean the screen and restore a well. Most techniques have provided some beneficial results, but all have also frequently failed to achieve substantial well improvements.

Well treatment typically includes the use of chemicals to break down encrusting materials. Mechanical techniques such as wire brushing, swabbing, jetting and surging can be used to assist the chemical treatment. The best well improvement results typically are obtained by the use of a properly selected combination of treatment methods.

High pressure jetting may be the most effective mechanical treatment method, preferably to get rid of softer encrustations, bio-films and iron slime. This type of jetting includes a self rotating nozzle head through which water is pumped with a high velocity. The pressure would typically be in the order 1 500-2 000 psi at a flow rate of 5-10 l/s. By pumping the well during the jetting the removed material is brought to the surface.

Acids are commonly used to chemically dissolve encrustation formed in a well. Acids can dissolve a number of mineral deposits. Although acids typically are not effective at killing bacteria, they are in general used to dissolve iron and manganese oxides formed because of bacteriological growth. Acid would also dissolve carbonate scales.

For iron bacteria and slime, a liquid hypochlorite would be effective. This strong oxidizer will also kill any bacteria. For clogs with carbonate scale, sulfuric acids are commonly used. For clogs with iron or manganese oxides, muriatic acid or hydroxyacetic acid may be a proper choice. The chemicals are pumped into the well and agitated frequently for 24 to 72 hours before it is recovered.

The use of dispersants, often polyphosphates, has sometimes been successful in improving the well performance due to mechanical blockage. Fine-grained materials can be dispersed by the dispersant and allow "sticky" particulates to disperse and move more freely in the formation pore space. In this way the pores can be cleaned from fines and eventually be pumped out of the well.

Implementation of rehabilitation procedures for an individual well should generally include the following steps:

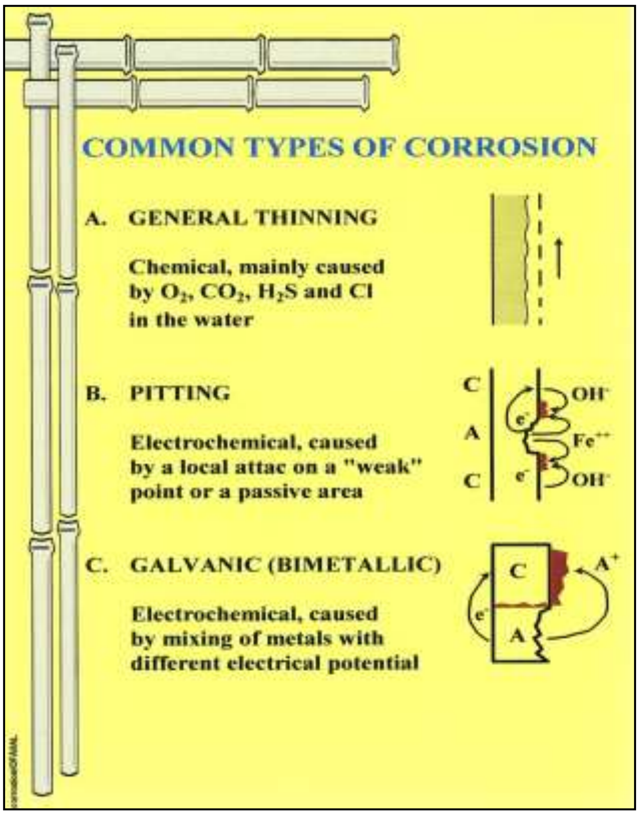
- Perform mechanical cleaning of the well screen
- Apply the proper quantity and type of chemical treatments
- Allow sufficient chemical reaction time
- Remove spent chemicals from the well
- Conduct a performance pumping test

All chemicals used during a well cleaning process must be carefully removed from a well and properly disposed. Water should be pumped from the well until the water quality is essentially the same as prior to treatment.

5. Problems related to corrosion

5.1 Types of corrosion

Compared to clogging, corrosion is less of a problem for wells and open loop system. Still, and under certain unfavorable conditions corrosion potential has to be considered in the design. The types of corrosion that may take place and the components that may be corroded are shown in figure 6.



Components sensitive for corrosion are:

Steel casings
Screens
Heat Exchangers

Fig.5. The concept for seasonal storage of natural heat and cold in the underground.

General thinning will affect al types of metals used in the system, just being a matter of time. However, noble metals such as titanium, that is sometimes used in heat exchangers will last extremely long before it is eaten up by corrosion. Heat exchangers made of stainless steel would also be highly resistant for general thinning. In stead, heat exchangers are sensitive for pitting corrosion, especially if salt water is used in the system.

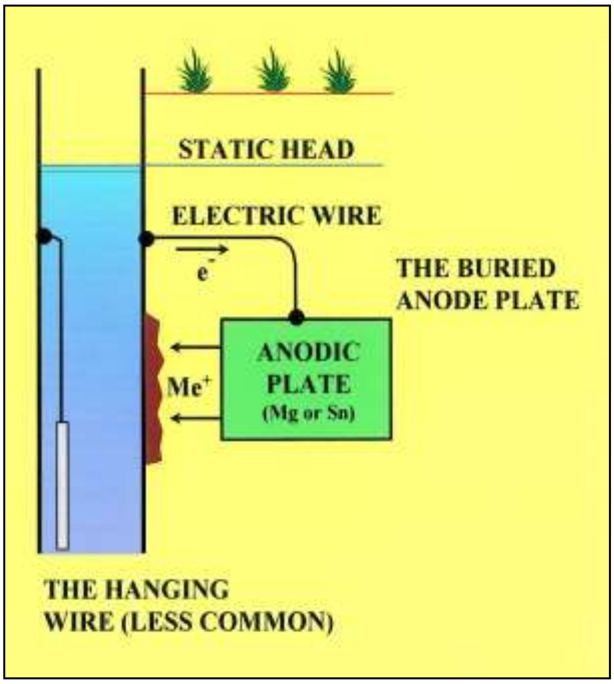
Screens that are made of stainless steel will have a long life time and will not be very sensitive for either general thinning or pitting corrosion. However, in this case the bimetallic type of corrosion may in rare cases corrode parts of the screen, especially in areas where the screen is in contact or close to the casing.

The most sensitive component would be the steel casing. Normally, the casing is made of carbon steel and has threaded or welded joints. These joints are also the most sensitive parts that commonly will have corrosion attacks caused by the pitting type of corrosion.

Water quality factors that increase the corrosion potential are preferably a low pH, a high content of salts, and dissolved gases like oxygen and hydrogen sulphite. The corrosion potential will also increase at turbulent flow and stagnant water conditions.

5.2 Corrosion prevention

To avoid corrosion problems the first choice would be to choose as noble material as technically and economically possible, and not to mix materials with different electrochemical potential, see figure 7



Corrosion problems can be limited by

Using corrosion resistant material, such as plastics and/or more noble metals/alloys

Not mixing materials with different electro chemical potential

Using cathode protection for wells with carbon steel casing

Figure 7. Measures for corrosion protection of wells open loop system components.

Other protection methods would be to use coated casing and pipes. This is done by a thin plastic or epoxy layer on the inside of the metal pipes. However, such films are sensible for mechanical damages and fits badly together with threads (or welding). Damages will, if they occur, lead to serious pitting corrosion attacks. It is therefore recommended not to use coated protections, especially not for well components, that are easily damaged during construction.

6.0 Aspects on maintenance

Open loop systems need to be systematically controlled, monitored and visually inspected in order to trace operational problems in an early stage, the earlier the better. The control should consist of visual inspections, monitoring of operational parameters and analyzes of the groundwater,

As suggested in figure 8, a simple way to check the function of wells is to monitor parameters that show the behavior of the wells. This could of cause be done manually by measuring the draw down, flow rate and injection pressure now and then, but the modern computerized controlling and monitoring systems makes it much simpler.

- **Use the monitoring system to keep a record of the specific drawdown and injection pressure (Q/s and Q/p) to check the status of the wells**
- **Keep a record of the temperature drop and pressure drop over heat exchangers connected to groundwater loop**
- **In systems with reversed flow, always back flush the wells used for injection before changing the flow direction**
- **By ocular inspections now and then, look for leakages, corrosion damages and status of monitoring meters**
- **Take water samples for chemical, bacterial and physical analyses, in order to detect changes causing operational or environmental problems**

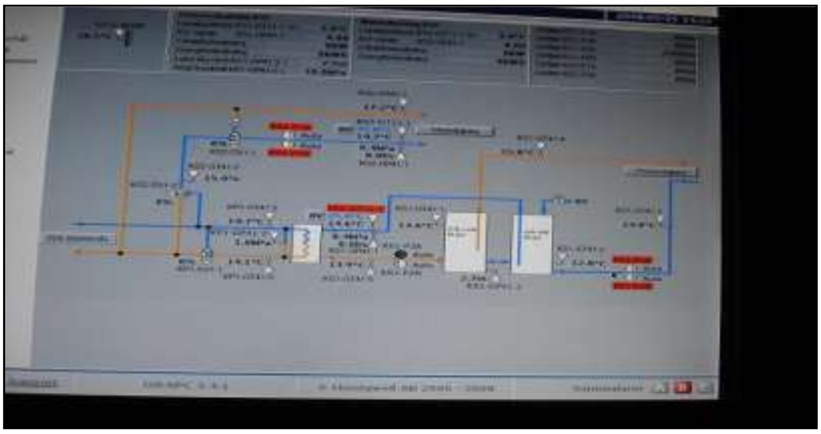


Figure 8. Guidelines for a maintenance program with inspections, data plotting and other measures

The visual inspections, a natural part of the maintenance program, should focus on regular visiting of well houses or cellars to (1) check for leakages, (2) the function and status of monitoring and controlling devices, (3) potential corrosion problems on equipment's and (4) the indoor status of well houses or cellars. This kind of inspections should be regular executed, once every quarter of a year or so.

When it comes to the operational parameters, there are often modern computer based controlling systems that makes it easier to monitor any misbehaviors in the system. These systems can also store and plot the operational parameters (flow rates, pressures and temperatures) that are very helpful for tracing potential well problems.

Since the water quality is essential for many reasons, not at least the clogging potential, it is of great value to take water samples for chemical, bacteriological and physical analyses on regular basis. In a maintenance program it should therefore be stated to do these types of analyses at least once a year.

Further information

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