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Project GEOCOND: Advanced materials and processes to improve performance and cost-efficiency of Shallow Geothermal systems and Underground Thermal Storage

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Abstract

The attempts to improve the efficiency of borehole heat exchangers (BHE) date back some decades. Some attempts like using metal tubes in the 1980s were limited by cost (and partly corrosion), and thin foil-type hoses did not withstand the rugged drilling environment. However, experiments with pipe size, double-U-tubes, thermally enhanced grout, etc. could bring the measure for the BHE efficiency, the borehole thermal resistance, from 0.20-0.15 K/(W·m) down to 0.08-0.06 K/(W·m) in the best solutions today. A further step cannot be expected without development of new, dedicated materials, combining the versatility of plastic like PE with an increased thermal conductivity that matches the respective properties of the rock and soil. This goal was e.g. included in the Strategic Research and Innovation Agenda of the European Technology Platform on Renewable Heating and Cooling in 2013.

The EU is now supporting a R&D-project aimed at finding and developing the desired materials, both for BHE pipes and for grouting materials. It is located at a relatively low level of technological readiness, with the final outcome to be materials produced prototypically in small amounts, suitable for the first tests in the intended environment. The project started on May 1st, 2017, and has a duration of 42 months. The main objectives are:

- Pipe Material: Development and testing of new pipe materials with improved conductivity and increased resistance to high temperatures, including also new coaxial geometries deemed more efficient and easier to install following a plug-and-play concept.
- Grouting Material: Development and testing of new technologies to improve thermal properties of the grouting of the Borehole Heat Exchanger. This includes improvement of the soil surrounding the Borehole Field, and the development of Phase Change Materials to be used in combination with UTES.
- The development of a respective Material Decision Support System.

The paper explains the research pathways envisaged, and the first results of the preparatory work leading to material formulation.

Keywords:

Borehole Heat Exchangers (BHE), Thermal Conductivity, Plastic Pipes, Grouting Material, PCM, Increased Efficiency, Cost Reduction

1. Introduction

Shallow geothermal energy systems, comprising Ground Source Heat Pumps (GSHP) and Underground Thermal Energy Storage (UTES), are exploiting a stable, reliable and renewable energy source with some key features compared to many other resources. However, its implementation at large scale presents some challenges, considering the high upfront capital needed compared to other solutions such as gas or other fossil technologies, the low awareness, and the diverse and changing regulations.

The new project GEOCOND aims at overcoming these challenges with a particular focus on capital cost reduction, increased efficiency, increased reliability & security, extended lifespan, improved environmental compatibility and increased awareness. Basic research on new materials and technologies in the key areas of GSHP and UTES will be combined with focused, system-wide engineering. By developing different material solutions, subsequently undergoing engineering, optimisation, testing and on-site validation steps, the GEOCOND partners are determined to substantially increase the thermal performance of the subsystems configuring a GSHP or UTES. The final goal, cost reductions of around 25% overall, will allow GSHP/UTES solutions to substantially gain competitiveness in the market.

The main components to be optimised are thermally enhanced pipe materials and grout mixtures for Borehole Heat Exchangers (BHE), exceeding the current state of thermal efficiency and greatly reducing borehole thermal resistance. Features like multi-layer pipe, forced grout injection into poor soil, or Phase Change Materials (PCM) embedded in the grout for UTES installations will be investigated and the possible merits quantified. In the subsequent chapters of this paper, the state-of-the-art and the different approaches and work packages are explained in more detail.

10 partners from seven countries (DE, IR, IT, SE, SP, TR, UK) work in the project; they represent mainly material sciences in plastics, cement, PCM, but also HVAC system engineering, shallow geothermal technology and geology:

- Universitat Politecnica de Valencia, Valencia, Spain
- AIMPLAS, Asocacion de investigacion de materiales plasticos y conexas, Paterna/Valencia, Spain
- RISE CBI Betonginstitutet AB, Stockholm, Sweden
- Sabançi Universitesi, Istanbul, Turkey
- Silma srl, Poggio a Caiano, Italy
- CAUDAL Extruline Systems S.L., Puerto Lumbrera, Spain
- Carmel Olefins Ltd., Haifa, Israel
- ÇIMSA Cimento Sanay ve Ticaret AS, Üsküdar Istanbul, Turkey
- UBeG Dr. Erich Mands und Marc Sauer GbR, Wetzlar, Germany
- Exergy Ltd, Coventry, England

More details on the partners and the project can be found on the website:
http://geocond-project.eu/

2. State of the art

2.1. The beginnings

The history of ground source heat pumps has recently been summarised in Sanner (2017). The first idea to use the ground as a heat source for a heat pump was published already in 1912 in a patent filed by Heinrich Zoelly. He envisaged a closed system, where the heat transfer fluid is circulated in pipes in the underground; the patent shows a helicoidal heat exchanger in a large-diameter hole (Figure 1, left). The first practical application of a ground heat exchanger recorded in literature was in 1945 in Indianapolis, USA, using horizontal pipes in the ground (3 circuits totalling 152 m) to supply heat to a compressor with 2.2 kW electric power input (Crandall, 1946). This was a direct-expansion system, i.e. the refrigerant of the heat pump circuit circulated directly in the buried heat exchanger pipes. Only two years later a paper (Kemler, 1947) presented a collection of ground-coupling technologies available at that time, among them three types of borehole heat exchangers (Figure 1, right); they comprise the basic geometries to which the BHE in use today can be ascribed to, i.e. co-axial, U-tube and helicoidal ("spiral").

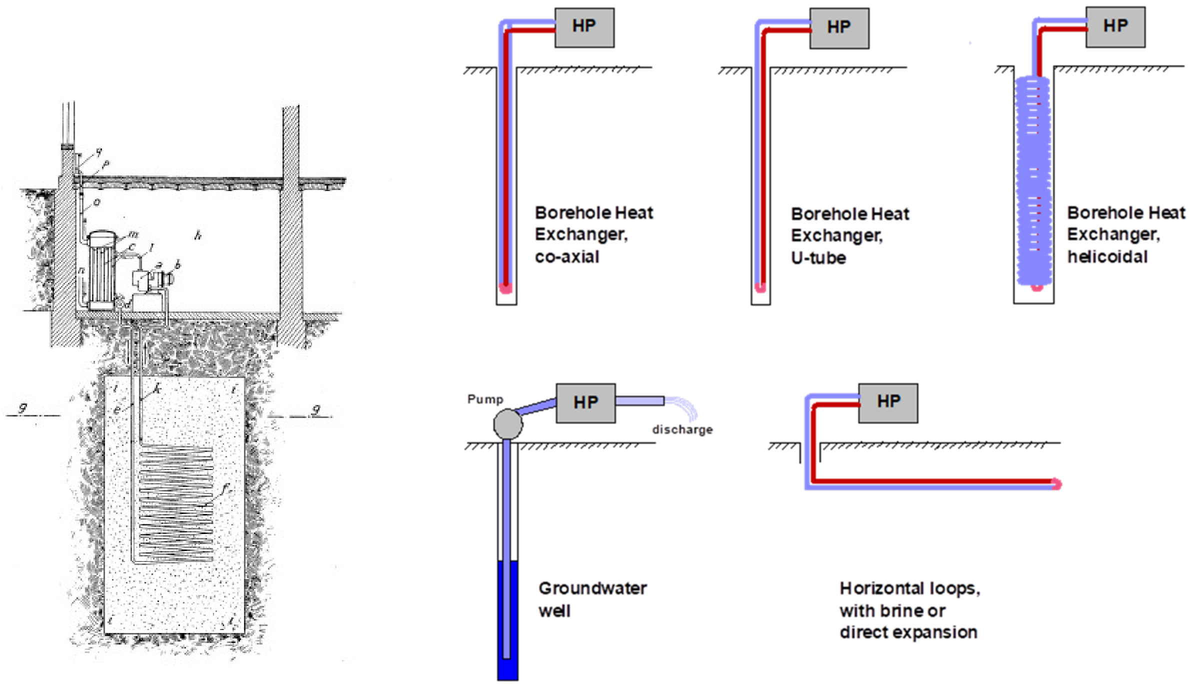

Figure 1: Left – Ground Source Heat Pump in Swiss Patent 59350 of 1912 (inventor H. Zoelly); Right – Ground-coupling methods listed by Kemler (1947), re-drawn and harmonised as in Sanner (2005)

The other option for ground coupling, using the groundwater as a heat carrier fluid in an open system, was also mentioned by Kemler (1947) (cf. Figure **1**).[1] In Europe an early plant of this type with 440 kW heating capacity is known from around 1950 in Thun, Switzerland (Zogg, 2008). All pre-dating heat pumps like the famous system for the Zurich town hall installed in 1938 were using water from rivers or lakes as a heat source, thus not qualifying as "geothermal" heat pumps as understood today in Europe (Definition in Article 2(c) of Directive 2009/28/EC: "geothermal energy means energy stored in the form of heat beneath the surface of solid earth").

In Germany, a first GSHP using horizontal loops became operational in 1969 (Waterkotte, 1972). The main GSHP development in Europe however was triggered by the first oil price crisis in 1973 (Sanner, 2017). The earliest GSHP with vertical loops (borehole heat exchangers, BHE) documented in Europe dates from 1974 in South-Western Germany (Moegle, 2009). Five BHE were installed in boreholes of 50-55 m depth in Schönaich (near Böblingen). The BHE were of the coaxial type, with rigid steel tubes 60×5 mm, screwed together by couplings, as outer pipes and a plastic hose as inner pipe. No grouting was performed, and water-glycol was used as heat transfer fluid. In 2005, after about 30 years of operation, one of the BHE leaked, probably due to corrosion. Other experiments with BHE in the 1970s are reported from UK, Netherlands and Sweden.

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[1] As project GEOCOND focusses on BHE only, open systems like groundwater heat pumps or Aquifer Thermal Energy Storage (ATES) are not further dealt with in this paper.

The first Swiss experiments with BHE also started around the same time, with the first modern BHE made of PE-pipes installed in 1980 (Rohner, 1991); Austria followed soon after. So when the second oil price crisis hit in 1980/81, heat pumps were available from factories large and small, mainly in Austria, France, Germany, Sweden, Switzerland, but also elsewhere, and the GSHP-technology to use the ground as heat source (and sink) had been demonstrated successfully.

2.2. Development of Underground Thermal Energy Storage

Early industrial use of underground thermal energy storage was reported by Sun et al. (1991). They described and evaluated several plants near Shanghai, China, dating from about 1960, where groundwater was used for cooling in the textile industry and re-cooling of the groundwater was performed in winter, making for an ATES system. First ideas to use ATES for storing solar energy were described by Brun (1964), while their use for storage of waste heat from power plants was first considered in the USA by Kazmann (1971); this kind of plants was intended for seasonal storage of heat from summer to winter. In Europe, experiments and test plants for ATES started in the 1970s, and on BTES a few years later, and the heat sources investigated comprised both solar heat and waste heat. Storage of cold from ambient air in winter for cooling purposes was considered only towards the end of the 1980s.

An analysis of the distribution of publications on UTES in the 1980s for the different storage options showed that ATES and BTES were fairly well balanced at that time. The development of UTES in general, and the state of the art in the beginning of the 1990s, is summarised in Bakema et al. (1995). For the field of high temperature UTES, an account of the different projects and experiences since the beginnings in the 1970s is given in Sanner (1999). In the 21st millennium the development shifted mainly to UTES for cold storage for building cooling, and numerous plants have been built in particular in Sweden and the Netherlands. Most large GSHP plants with BHE, of which the majority can be found in Scandinavia, Switzerland and Germany, have at least a UTES component, as more heat is exchanged with the underground inside the BHE field than is extracted from or injected into the surrounding geological layers. In recent years also high temperature UTES finds renewed interest, e.g. as BTES for storage of industrial waste heat (Nordell et al., 2016), and in combination with deeper boreholes.

2.3. State-of-the-art in materials for pipes and grout

After the early period of experimentation with various metal and plastic materials, and with the emergence of factory-made BHE coils on the market in the late 1980s, high-density polyethylene (HDPE) became the preferred material for decades. The main advantages were cost, easy handling incl. welding, and longevity. The evolution went from PE80 to PE100 and PE100-RC, and later included cross-linked polyethylene (PE-X), once the challenges for connections (and bending of the BHE footpiece) could be handled. Other materials than PE were only used when required by high temperatures in BTES, making a case e.g. for Polybutylene (PB) at operating temperatures up to 70 °C. A recent review of pipe materials for BHE was published by Mendrinos et al (2017), giving an overview also of other potential materials. Some of the materials listed in that paper fall out of the range of viable, reasonably priced options, as they are deemed to be not suitable for producing pipes by extrusion.

A table in the draft version of the new edition of guideline VDI 4640-2 [2], published in May 2015, lists the pipe materials recommended for use with BHE (Table 1). This can be considered as industry best practice at the time of ENERSTOCK 2018. In France, standards NF X10-960-2 to NF X10-960-4 deal with PE100, PE-X and PE-RT, while in Italy standards UNI 11466 to UNI 11468, in Spain standard UNE 100715-1, and in Switzerland standard SN 565 384/6 also mention PE100 as the typical material. And Mendrinos et al (2017) conclude: *"… HDPE is the most competitive option due to its low price and its moderate thermal conductivity"*.

Table 1: Pipe material properties, selected values from VDI 4640-2 (2015)

Material	Thermal conductivity	Maximum operating temperature for 50 years pipe lifespan *	Maximum operating temperature for 1 year pipe lifespan *
PE100	0.42 W/(m·K)	40 °C	70 °C **
PE100-RC	0.42 W/(m·K)	40 °C	70 °C **
PE-RT	0.42 W/(m·K)	70 °C	95 °C
PE-X	0.41 W/(m·K)	70 °C	95 °C
PA	0.24 W/(m·K)	40 °C	70 °C
PB	0.22 W/(m·K)	70 °C	95 °C

* at given maximum pressure conditions ranging from 0.6-1.2 MPa

** even short-time excess temperatures can damage pipes

Metal pipes for BHE have been suggested since long, in view of the substantially higher thermal conductivity compared to plastics, and have been used in several cases. However, the issues of corrosion and of unit cost for non-corrosive metals was considered an obstacle. In situ corrosion tests carried out in 1986-1988 in a groundwater well at Schwalbach GSHP research station yielded the values given in Table 2 (Sanner, Knoblich, 1991). The conclusion was that service lifetimes of 30-40 years could be expected with plain steel and copper, and no measurable short-term corrosion with stainless steel. This is compatible with the values given in table 7 of Mendrinos et al (2017), showing service lifetimes for galvanised steel tubes (somewhat better protection than plain steel) of about 50 years. For metals in general, Mendrinos et al (2017) conclude: *"In geologic formations characterized by low to moderate corrosive potential, stainless steel, aluminum and copper are good metallic alternatives to HDPE … Galvanized steel pipes may also provide competitive alternatives to HDPE in such environments"*.

In practice, HDPE-pipes dominate the market in Europe, with other plastic materials and metals reduced into a tiny niche. The main reasons are:

- Cost and corrosion – Plastic pipes have superior corrosion resistance compared to plain metals in the same cost range, and corrosion-resistant metals like stainless steel are much more expensive.
- Handling – BHE made of plastic pipes can be delivered to the drilling site in coils, factory-finished and for the full length, while most metals would mean sections of rigid steel tubes of the maximum length fit for transport and installation, and connecting

[2] VDI 4640 is a widely respected industry standard in Germany and neighbouring countries, first published in 1998, and now comprising 5 parts for different aspects of shallow geothermal energy.

(welding/screwing) of the sections during installation on site. Furthermore, these connections of metal pipes are more susceptible to either corrosion or leakage than connections by welding of HDPE. Corrugated metal tubes with thin walls e.g. from stainless steel could also be pre-fabricated and coiled, but at much higher cost.

Table 2: Results of in-situ corrosion tests in 1986-88 (Sanner, Knoblich, 1991)

Material	Weight loss per year
pure iron	2.20 %
steel St37	2.15 %
copper	1.74 %
stainless steel	0.00 %

In conclusion on the state-of-the-art of BHE, plastics like HDPE are the material of choice today and in the foreseeable future. For the most common type of BHE, the U-tube design (single, double or more), it is highly unlikely that metal alternatives will have a share in the market. Looking at coaxial or helicoidal designs, there might be some place for non-plastic alternatives in boreholes with limited depth.

The early BHE had no grouting, they were either immersed in groundwater in open holes, or filled by gravity from top (often using the drill cuttings as filling material). In softer geological layers, the ground was allowed to collapse around the pipes after installation, and in other cases steel pipes were driven directly into the ground, with no annulus. Inserting BHE-pipes into open, water-filled boreholes in hard rock, with just the softer overburden stabilised by a steel tube, still is the norm in most of Scandinavia.

Grouting of BHE by pumping a mixture down a tremie pipe and filling the annulus from bottom to top was presumably first done in Switzerland and in USA in the late 1980s. The first standard to require grouting from bottom to top of the borehole was AWP T1 (1992) in Switzerland. The first German standard on GSHP, VDI 4640-2 (1998), also recommended grouting, but still left room for some exceptions for shallow boreholes. The grout mixtures originally consisted of bentonite, cement and water; VDI 4640-2 (2001) gave an example with 25% bentonite, 25% cement and 50% water, resulting in a thermal conductivity of about 0.7-0.8 W/(m·K).

The supposedly first publication on the idea of grout with enhanced thermal conductivity is Remund, Lund (1993). In the mid-1990s, a thermally enhanced grout came on the market in the USA, with a thermal conductivity of almost 1.5 W/(m·K); in American units, this means 0.85 Btu/(hr·ft·°F), leading to the name of thermal grout 85. The increase in thermal conductivity was achieved by adding siliceous sand. Experiments in 1996-1999 at Brookhaven National Laboratory in USA targeted different additives for increased thermal conductivity, beside siliceous sand also steel grit, steel microfibers and aluminium oxide; siliceous sand was found the only viable option (Allan, Philippacopoulos, 1999). Developments in Germany around 2000 resulted in grout mixtures with addition of either quartz powder or graphite, under the brand names Stüwatherm and Thermocem, respectively. Also in VDI 4640-2 (2001) the addition of quartz sand was suggested to improve thermal properties.

In the meantime, numerous brands of grout ready for use are on the market. The thermally enhancing additives are either siliceous sand, quartz powder or graphite. The addition of magnetite in one product is not made to enhance thermal properties, but for allowing quality control of grouting through magnetic susceptibility measurements. Recent tests with aluminium added delivered thermal conductivity up to 3 W/(m·K) (Sáez Blázquez et al, 2017), but are deemed not to meet other grout requirements yet, without use of bentonite. A specific issue at least in Germany is the behaviour of the grout during freezing-thawing-cycles (Anbergen et al, 2012), when damage of the grout texture and increase of hydraulic permeability (loss of sealing properties) may occur. In draft VDI 4640-2 (2015), a routine for testing the grout while freezing is proposed in appendix C. Any new mixtures with enhanced thermal conductivity will have to meet also the sealing requirements.

3. In pursuit of efficiency

3.1. Development at the end of the 20th century

The pursuit of increased heat exchange efficiency with ground heat exchangers started early. The first German BHE installation in 1974 (Moegle, 2009) used steel tubes, and attempts then were made to combine the advantage of high thermal conductivity of metal with a continuous pipe that can be coiled and does not need the connection of individual, rigid tubes. A German company brochure (WTA, 1981) shows photos of drilling and installation for a coaxial BHE, made from corrugated stainless steel for the outer pipe, and a rubber hose for the inner pipe. This design was improved by another company (Helmut Hund GmbH) using a thin PE-coating extruded under vacuum to the outer pipe wall, in order to provide corrosion protection with as little temperature drop as possible (Figure 2). In Switzerland, where Double-U-BHE made from PE are the norm since the early 1980s, an improved coaxial design (Figure 3) was successfully tested and used for some years. Alas, the higher cost of the bespoke extrusion compared to standard PE-pipes in U-tube designs were not set off by the better performance, at least not at that time.

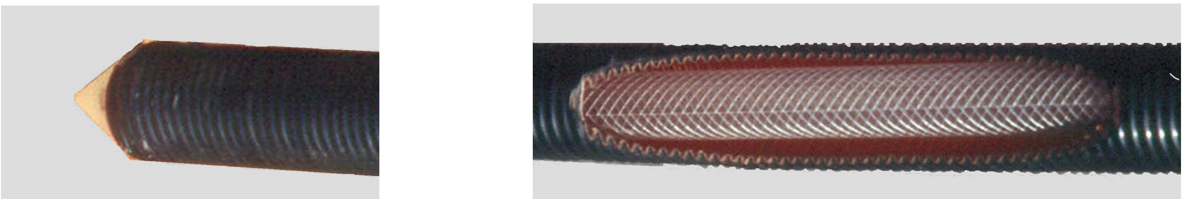

Figure 2: Coaxial BHE as tested in Schwalbach GSHP research station (Sanner, 1986), consisting of corrugated metal outer tube (usually stainless steel, but copper in this cut-out sample for exhibitions), protected against corrosion by a PE-coating

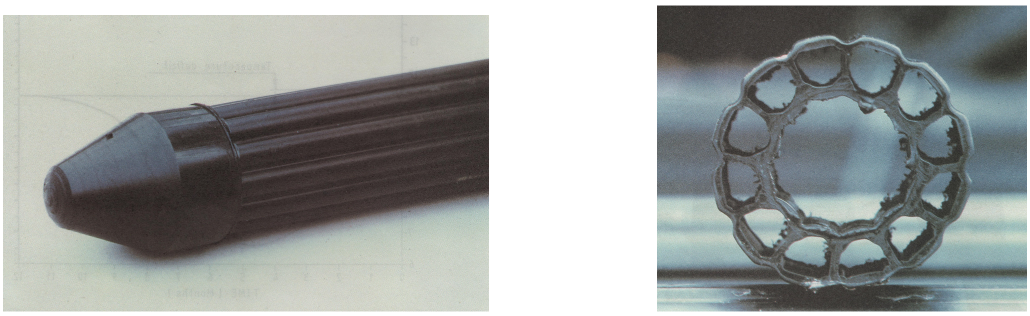

Figure 3: Coaxial BHE by SHF in Switzerland, made of PE with multi-chamber outer channel for turbulent flow and increased heat exchange (photos from Hess, 1987)

The most efficient BHE of the 1980/90s probably was a type of coaxial BHE used e.g. in a BTES-experiment in Luleå in Northern Sweden (Nordell, 1994), where the borehole wall in solid rock provided the outer boundary and only an inner pipe had to be inserted (Figure 4). This technology of course only works in very stable rocks and with water as heat carrier fluid, that can be in exchange with groundwater in fissures and fractures. This technology thus has not found much replication, and experiments with hoses made of plastic foil used to tighten the borehole walls ("liner"in Figure 4) in another Swedish BTES in Anneberg near Stockholm (Lundh, Dalenbäck, 2008) in 2002 were not quite successful.

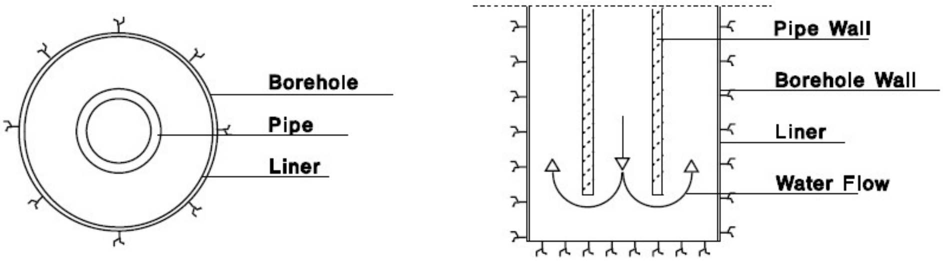

Figure 4: Coaxial BHE in open borehole (with or without liner, depending on rock quality) as used in Luleå BTES, constructed 1982/83 (graph from Nordell, 1994)

3.2. Considerations on pipe material

After HDPE proved to be an easy-to-use and reliable material, development focused mainly on improving the resistance of the material to pressure, temperature, damage (like from scratching), corrosion, etc., resulting in the materials listed in Table 1. The thermal conductivity on the order of 0.4 W/(m·K) was accepted as suitable, albeit not being ideal. Considering the thermal efficiency of the whole BHE-system, from surrounding ground to the fluid inside the pipes, thermal conductivity is only one factor of many. Furthermore, for the whole GSHP or UTES facility, the efficiency of BHE again is just one factor, with the physical properties of the ground being likewise important – and ground thermal conductivity typically is in a range of 0.5-4.0 W/(m·K), and not one or two orders of magnitude higher as most metals exhibit. The overall efficiency of a BHE usually is given by the borehole thermal resistance r_b, expressed in K/(W·m) and comprising the individual resistances from borehole wall to fluid (Figure 5).

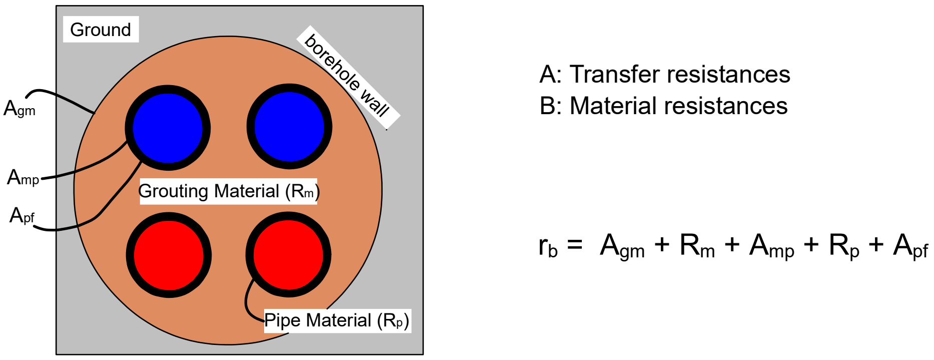

Figure 5: Components of borehole thermal resistance r_b for a double-U-BHE

Parameter studies showed the influence of pipe material on the overall BHE efficiency. Such modeling was made e.g. in 2003 within project Groundhit, funded by the EU in FP6 (Sanner et al, 2007). Figure 6 shows the results of the Groundhit parameter study, re-calculated in

2017 with the latest version of EED (4.16) and with an assessment for helicoidal BHE added. The calculations are based on the values given in Table 3. The flow volume inside the pipes was adjusted to always guarantee a turbulent flow (in the case of coaxial BHE only in the annulus between inner and outer pipe). In EED, performance for helicoidal BHE currently can only by assessed by approximation to a coaxial BHE with the annulus between outer and inner pipe representing the fluid inside the “spiral” part of the helicoidal BHE. Projects dedicated especially to helicoidal BHE soon will provide both better modelling tools and validation for this type of BHE.

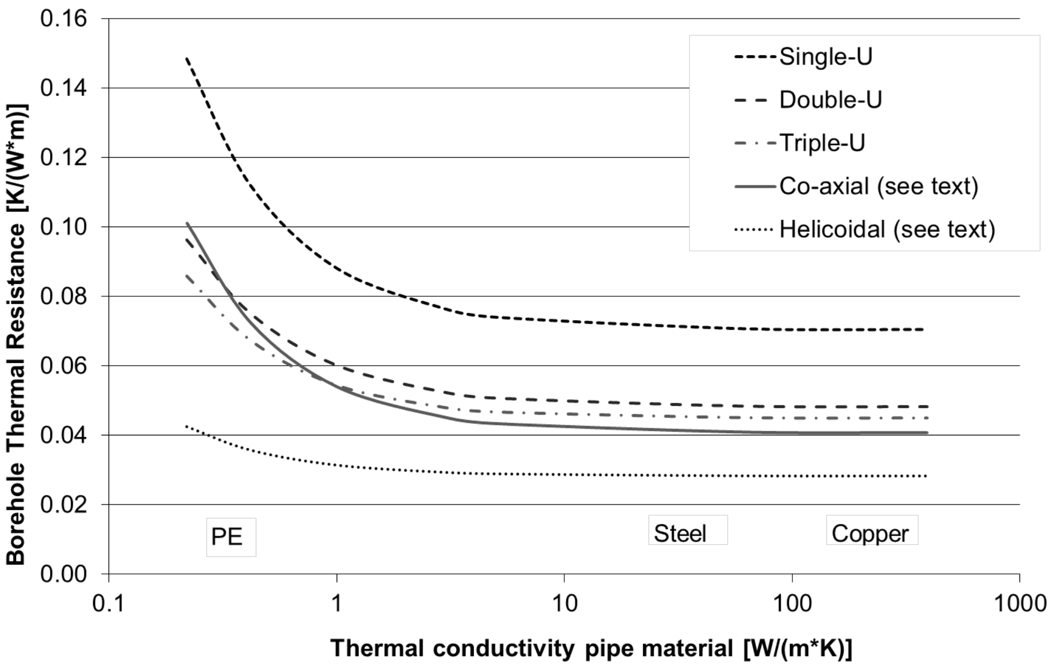

Figure 6: Borehole Thermal Resistance r_b for different configurations versus thermal conductivity of pipe material, see text for details; helicoidal by approximation only

Table 3: Input data for parameter study shown in Figure 6 (original Groundhit data from 2003 for U-tube and coaxial BHE, helicoidal added in 2017)

	U-tube BHE	Coaxial BHE	Helicoidal BHE
Borehole diameter	150 mm	150 mm	400 mm
Pipe diameter	32 mm	100/60 mm *	32 mm
Wall thickness	3 mm	4 mm	3 mm
Outer diameter of “spiral” (helicoidal BHE only)			300 mm
Thermal conductivity of grout (for all)		1.8 W/(m·K)	
Thermal cond. of surrounding ground (for all)		2.5 W/(m·K)	

* outer/inner pipe

The results in Figure 6 show clearly that an increase in thermal conductivity of the pipes from about 0.2 W/(m·K) to 1 W/(m·K) can reduce r_b substantially, and a reduction on a smaller scale can be seen up to 4-5 W/(m·K); for further increase of thermal conductivity into the realm of metals, the reduction of r_b is only marginal.

3.3. Considerations on grouting material

Similar parameter studies as with pipe material can be made for the grout. The practical range of thermal conductivity for grout is much smaller, extending from around 0.6 W/(m·K) with some plain bentonite-cement mixtures to slightly above 2 W/(m·K) in currently available materials. A further increase would require new concepts, and considering the other material constraints for sealing properties and cost, more than a doubling of the current achievement seems out of reach. Thus for the calculations resulting in the curves in Figure 7, the thermal conductivity of the grout was varied from 0.5-8.0 W/(m·K), and the pipe thermal conductivity fixed at the value for HDPE, 0.42 W/(m·K). All other input data are as shown in Table 3.

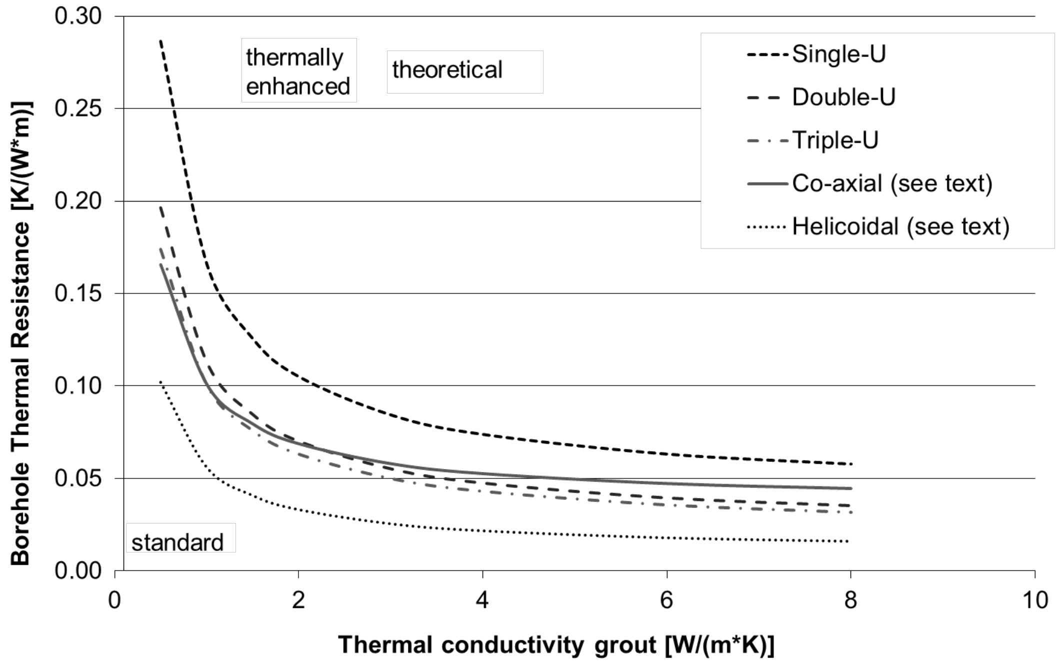

Figure 7: Borehole Thermal Resistance for different configurations versus thermal conductivity of grout (backfilling); helicoidal by approximation only

Like for pipe material, a substantial improvement (decrease of r_b) can be seen for grout thermal conductivity increasing to about 2 W/(m·K). A further reduction of r_b is visible towards values of 4 W/(m·K) for most configurations; the effect is highest for single-U and lowest for the already very low r_b of helicoidal BHEs. Additional increase in grout thermal conductivity has little visible effect only. For all U-tube configurations, the better thermal performance of the grout means not only better heat exchange to the surrounding ground, but also an increase in thermal short-circuiting between supply and return pipes. Other means like insulation between pipes would be required, adding to the complexity of system and installation.

These basic findings were experimentally confirmed by Go et al (2014), with the conclusion: "*The grout thermal conductivity has a great influence on the borehole thermal resistance. However, when the thermal conductivity of the grout becomes considerably higher, the borehole thermal resistance will assume a constant value, …*".

Validation of the effect of grout thermal conductivity in practice had already been done shortly after the first thermally enhanced grouting material became available in Europe in 2000. Values for r_b from 14 TRT on BHE with standard grout (bentonite-cement-mixtures) and 17 TRT on BHE with thermally enhanced grout, made in 1999-2004, were collected and plotted against the respective borehole diameter (Figure 8). While the values are distributed over a wide range, probably due to variation in BHE type, shank spacing, grouting quality, etc., two distinct groups can be identified with mean values close to the expected values from calculations.

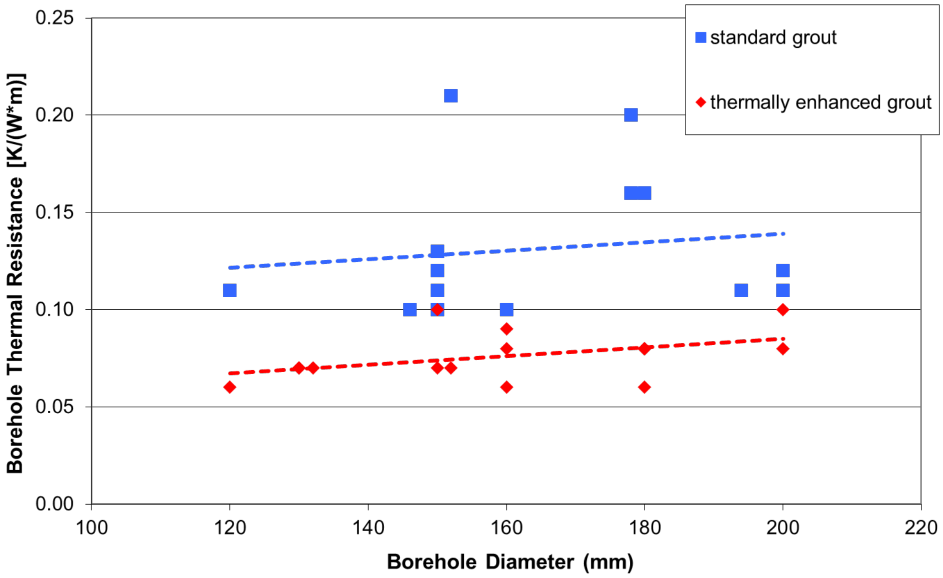

Figure 8: Borehole Thermal Resistance from 31 TRTs made in Germany in 1999-2004, BHE grouted with standard or thermally enhanced grout (after Sanner et al, 2005)

3.4. Overall BHE efficiency

The borehole thermal resistance r_b (cf. Figure 5) is a good measure for the efficiency of a single BHE, with low values indicating small temperature losses between the ground and the fluid inside the BHE. For the whole GSHP system, further factors need to be included, like ground thermal conductivity, thermal interaction of BHE, permissible temperature drop/increase, operating hours and patterns, etc. Here the concept of Hellström-efficiency η_H comes in handy, a relative measure of heat transfer efficiency of a specific BHE system and thus a good tool to compare different installations (Mands et al, 2009). For determining η_H, the maximum sustainable heat extraction/injection rate (or the total required BHE length) is calculated for the individual GSHP installation, using suitable tools like EED, and compared to the theoretically achievable heat extraction/injection rates (or required BHE length) for a system with the hypothetical value of $r_b = 0.0$ K/(W·m):

$$\eta_H = \frac{\text{maximum sustainable heat extraction rate, calculated with real values}}{\text{maximum sustainable heat extraction rate calculated for } r_b = 0} \times 100 \qquad \text{[in \%]}$$

In Figure 9 the sustainable heat extraction rate and Hellström-efficiency are shown for a sample GHSP with 10 kW heating capacity, 1800 full-load hours per year, and ground thermal capacity $\lambda = 2.5$ W/(m·K). The calculation was done for 8 short BHE (10-20 m) and 1 long BHE (>100 m), respectively. In this scenario, a state-of-the-art double-U-BHE with thermally enhanced grout achieves a value of 60-65% for η_H. The Hellström-efficiency allows to compare BHE designs and evaluate the limitations – designs with alleged specific heat extraction rates that would result in $\eta_H > 100\%$ are not sustainable.

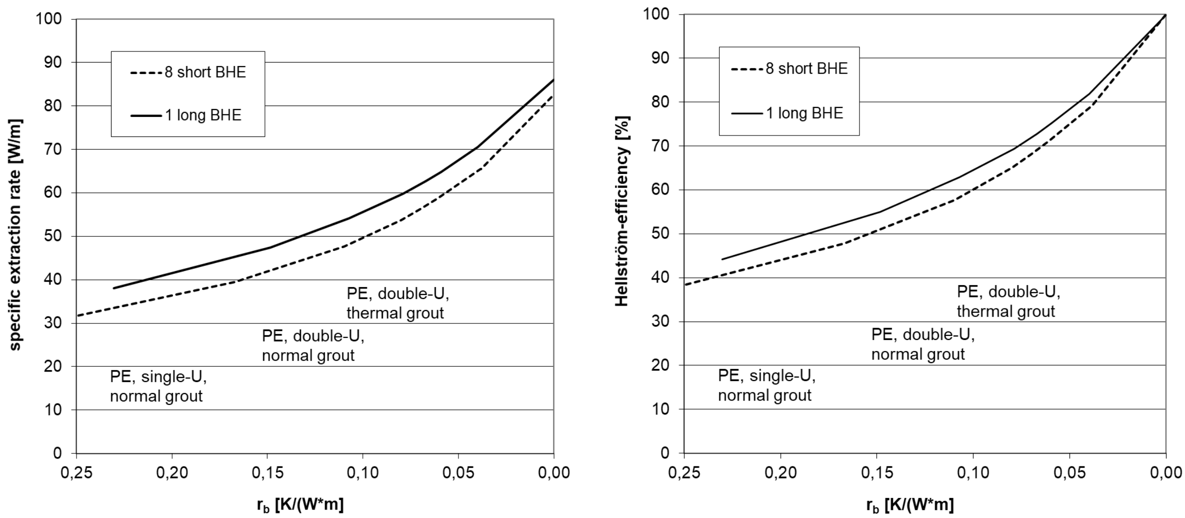

Figure 9: Achievable specific heat rate in a sample GSHP (left) and concept of Hellström-efficiency η_H (right, see text); plotted against r_b-value, areas of typical BHE-types indicated

4. Project GEOCOND approach

4.1. Basic goals and performance indicators

In order to pave the way for a higher overall efficiency of the BHE, three different areas must be addressed, as listed in Table 4. They comprise both the individual materials for pipe and grout, and furthermore look at the overall system and the interaction with the surrounding ground. The roadmap and timeline for the work is shown in Figure 9. With this approach GEOCOND is developing a smart combination of materials for GSHP and UTES, and aims to achieve in the field of economic competitiveness:

- up to 20 % reduction of borehole length
- up to 25 % reduction in CAPEX
- up to 15 % increased longevity
- up to 15 % reduction in OPEX

Table 4: The different technical areas of GEOCOND

Area	Approach	Goal
BHE pipes	Plastic pipes and fitting elements with high thermal conductivity	2x higher thermal conductivity compared to currently commercial HDPE pipes
BHE grouting	New high conductivity borehole filling (grouting) materials, including low temperature PCM*	12% lower borehole thermal resistance and higher heat storage capacity
BHE system	Tailor-made solutions for grouting materials and innovative pipes configuration	20% reduction in borehole length

* Phase Change Materials

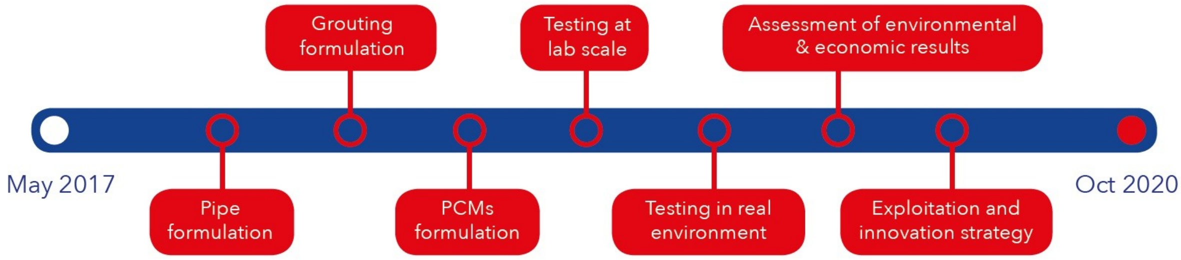

Figure 10: Timeline of project GEOCOND

In the common roadmap of the RHC-Platform (RHC-ETP, 2014), some key performance indicators for shallow geothermal installations are stated:

SG1. *A Seasonal Performance Factor in the order of 5 for 2020.*

SG2. *A Hellström-efficiency (a measure of the impact of borehole thermal resistance) of about 80% in 2020.*

SG3. *A further decrease in energy input and reduced costs for operating the geothermal heat pump system.*

GEOCOND is contributing to all these goals. For a high SPF, an efficient ground-coupling system (in this case BHE) is a prerequisite. Concerning the Hellström-efficiency (see chapter 3.4), the η_H-values did increase from below 60% to almost 75% over the past 10 years, and GEOCOND is aiming to approach values >80% by means of new materials and geometries. And the energetic and economic expectations have been already stated above.

4.2. Individual technical goals

At this stage, the target materials and additives cannot yet be disclosed; however, the main pathways are:

- Development of pipe materials is towards geothermal pipes with customized thermal conductivities and improved performance. This does not only include higher thermal conductivity, but addresses also low-conductive materials for inner pipes in coaxial BHE, lower resistivity to flow at the inside and better bounding to the grout on the outside.
- On the grout side, development follows several routes: New additives for grouts to increase thermal conductivity and provide tailor-made performance while improving handling and bounding characteristics; inclusion of phase change materials (PCM) in additives to enhance thermal storage capacity, in particular for UTES applications; and injecting the grout also in pores, fissures and fractures to improve the thermal characteristics of the surrounding ground (Thermal Soil Enhancement, TSE).

Validation of performance increase will be done in two steps in 2019-2020, first with samples of ca 15 m length in a well-explored test field at the Universitat Politecnica de Valencia, and then in the frame of some real BHE installations in Germany and Finland. The whole activity is accompanied by investigation of environmental, social and economic feasibility of the concepts.

A Material Selection Support System, based on multi-objective simulation and optimisation within a simulation software, is under development to allow rational selection of best material specifications for a range of applications.

5. Outlook

Project GEOCOND aims at improving substantially the operational efficiency of BHE systems by optimising the materials for individual components (pipes, grout) and the overall setup. This improvement in technical efficiency shall be translated into cost savings in installation and operation, allowing for a leap in economic benefits of shallow geothermal technology. Furthermore, a significant reduction of the drilled meters and the amount of pipes used to fulfil the same heating and cooling needs enables a decrease of environmental impact.

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