Project GEOCOND: Advanced Materials and Processes to Improve Performance and Cost Efficiency of Shallow Geothermal Systems and Underground Thermal Energy Storage

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ABSTRACT

The EU is supporting a R&D-project aimed at finding and developing optimised materials, both for Borehole Heat Exchanger (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 BHE. 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.

This paper explains the research pathways envisaged, the parameter studies to define the required characteristics, and an overview of the first results achieved. More details on some specific results are presented in an additional, separate paper, including also related work done outside the project, on creating thematic maps with the relevant information (geological, lithological, geothermal) for checking the suitability of the envisaged improvements to the respective site conditions: "*GIS-supported evaluation and mapping of the physical parameters affecting shallow geothermal systems efficiency at a continental scale*" (Ramos-Escudero et al., 2019), paper #287 in EGC 2019.

1. INTRODUCTION

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 (ETP-RHC 2013).

Project GEOCOND aims at advancing beyond the status achieved today, by basic research on new materials and technologies in the key areas of ground source heat pumps (GSHP) and underground thermal energy storage (UTES), 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 BHE. The final goal, cost reductions of around 25% overall, will allow shallow geothermal solutions to substantially gain competitiveness in the market.

The main components to be optimised are thermally enhanced pipe materials and grout mixtures for 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 are investigated and the possible merits quantified. In the subsequent chapters of this paper, the state-of-the-art, the different approaches and work packages, and some first results are explained in more detail.

10 partners from seven countries (DE, IL, 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 Sanayii ve Ticaret A.Ş, 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 State-of-the-art of BHE pipes

Application of BHE for shallow geothermal energy use dates back to the 1940s (Sanner, 2017). The pursuit of increased heat exchange efficiency with ground heat exchangers started in earnest when GSHP and BHE were tried in Europe after the first oil-price crisis in the 1970s. 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 1). In Switzerland, where Double-U-BHE made from PE are the norm since the early 1980s, an improved coaxial design (Figure 2) 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.

After this 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 said paper fall out of the range of viable, reasonably priced options, as they are deemed to be not suitable for producing pipes by extrusion.

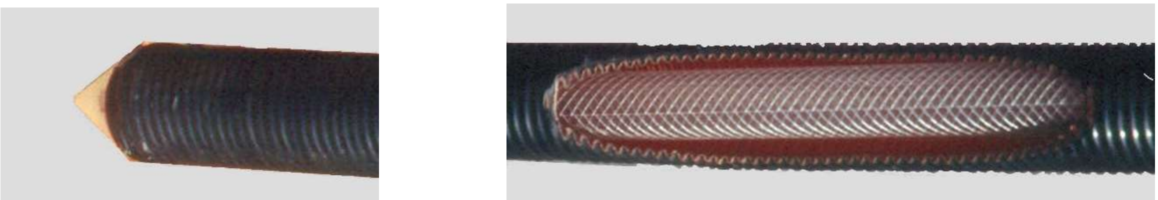


Figure 1: Coaxial BHE as tested in Schwalbach GSHP research station (Sanner, 1986), consisting of corrugated metal outer tube (usually stainless steel, but copper in this cut-out sample for exhibitions), protected against corrosion by a PE-coating (photos Sanner)

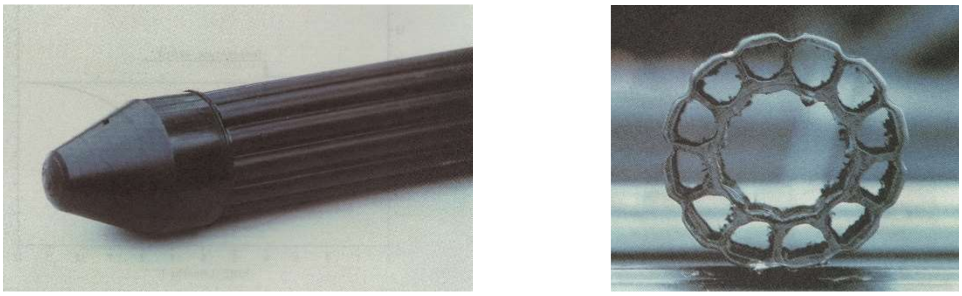


Figure 2: Coaxial BHE by SHF in Switzerland, made of PE with multi-chamber outer channel for turbulent flow and increased heat exchange (photos from Hess, 1987)

A table in the draft version of the new edition of guideline VDI 4640-2, published in May 2015, lists the pipe materials recommended for use with BHE (Table 1). This can be considered as industry best practice today. 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: Thermal conductivity of BHE pipe material, from VDI 4640-2 (2015)

Material	Thermal conductivity
PE100	0.42 W/(m·K)
PE100-RC	0.42 W/(m·K)
PE-RT	0.42 W/(m·K)
PE-X	0.41 W/(m·K)
PA	0.24 W/(m·K)
PB	0.22 W/(m·K)

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 and 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.

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

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

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 (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.

In conclusion on the state-of-the-art of BHE pipes, 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.

2.2 State-of-the-art of BHE grouting

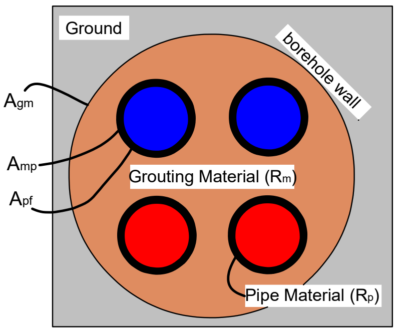
The supposedly first publication on the idea of grout with enhanced thermal conductivity is Remund and Lund (1993). In the mid-1990s, a thermally enhanced grout came on the market in the USA, with a thermal conductivity of almost 1.5 W/(m·K); in American units, this means 0.85 Btu/(hr·ft·°F), leading 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 and 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. DELIBERATIONS ON REQUIREMENTS AND MATERIAL PROPERTIES

3.1 Material requirements for BHE pipes

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 3).



$$r_b = A_{gm} + R_m + A_{mp} + R_p + A_{pf}$$

A: Transfer resistances

B: Material resistances

Figure 3: 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 modelling was made e.g. in 2003 within project Groundhit, funded by the EU in FP6 (Sanner et al, 2007). Figure 4 shows the results of the Groundhit parameter study, re-calculated in 2017 with a newer 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.

The results in Figure 4 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.

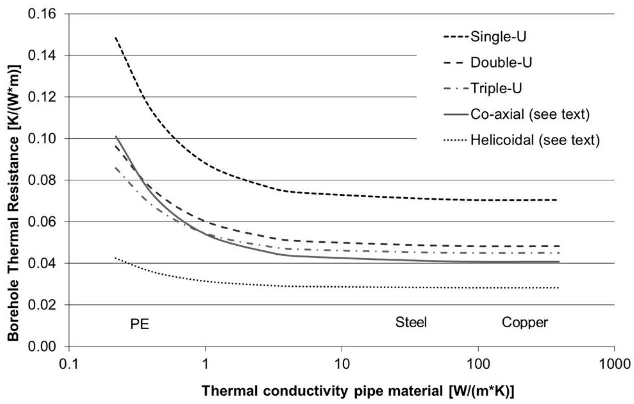


Figure 4: Borehole Thermal Resistance r_b for different configurations versus thermal conductivity of pipe material, see text for details; helicoidal by approximation only

Table 3: Input data for parameter study shown in Figure 4 (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

In project GEOCOND, further parameter studies with a large variation of input parameters for pipe material were made (cf. chapter 5.1), in order to determine the optimum thermal properties of pipes for the different BHE geometries. For other important properties that have to be fulfilled, European standards (EN) as well as standards and guidelines from France, Germany, Italy, Spain, Switzerland and the UK were studied. These standards allowed to identify some requirements for pipes during production, installation and operation (including long-term stability). A key goal of project GEOCOND is to improve thermal conductivity of pipe materials while maintaining the proven and suitable other properties of plastics like PE100, as stipulated in these standards. However, for most pipe materials in use with shallow geothermal installations, no specific requirements in terms of exact physical values or test procedures are given, hence materials as used today are instead applied as benchmarks.

3.2 Material requirements for BHE grout

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 Fig. 5, 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.

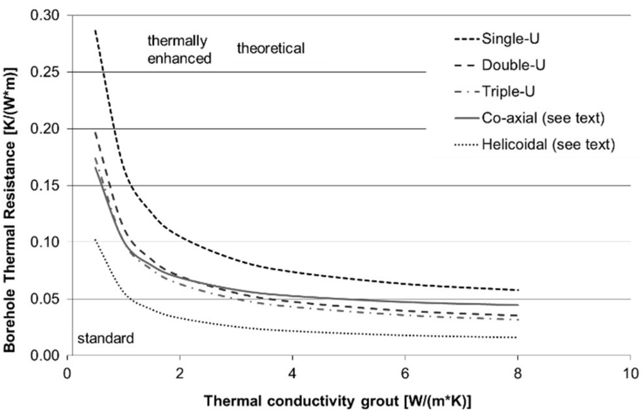


Figure 5: Borehole Thermal Resistance for different configurations versus thermal conductivity of grout (backfilling); helicoidal by approximation only

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 used. While the values are distributed over a wide range, probably due to variation in BHE type, shank spacing, grouting quality, etc., two distinct groups could be identified with mean values close to the expected values from calculations (Sanner et al., 2005).

In project GEOCOND, further parameter studies with a large variation of input parameters for grout were made (cf. chapter 5.1), in order to determine the optimum thermal properties of grout for the underground conditions prevailing in the European countries. The maps and statistics described in Ramos-Escudero et al. (2019) provided the underground information and helped to match these theoretical parameter studies with the real underground situation. For other important properties that have to be fulfilled, standards and guidelines from France, Germany, Italy, Spain, Switzerland and the UK were studied. These standards allowed to identify the requirements before installation (rheology, important for handling, pumping, flowing, etc. during the grouting process) and after installation (sealing, resilience to freezing/thawing, etc., issues important for environmental protection).

3.3 Overall BHE efficiency

The borehole thermal resistance r_b (cf. Figure 3) 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):

$$\eta_H = \frac{\text{maximum sustainable heat extraction rate, calculated with real values}}{\text{maximum sustainable heat extraction rate calculated for } r_b = 0} \times 100 \text{ (in \%)} \qquad [1]$$

In Figure 6 the sustainable heat extraction rate and Hellström-efficiency are shown for a sample GSHP with 10 kW heating capacity, 1800 full-load hours per year, and ground thermal capacity λ = 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.

For BHE, all geometries can be grouped into two basic patterns, U-tube and coaxial, with the latter further subdivided into simple coaxial, complex coaxial and helicoidal (Fig. 7). In project GEOCOND all these classes are addressed, with a specific emphasis on pipes for U-tube and simple coaxial, as these comprise the vast majority of installations. The advantages and limits of the different BHE geometries are evaluated; several configurations have specific advantages for either use with deep boreholes, large-diameter shallow boreholes, or other. Double-U-tube BHE as the current economic optimum in most countries are still susceptible to optimisation, and coxial (and for certain applications helicoidal) BHE can offer good potential for improved efficiency. Optimisation of geometry will mainly be done by simulation (cf. chapter 5.1).

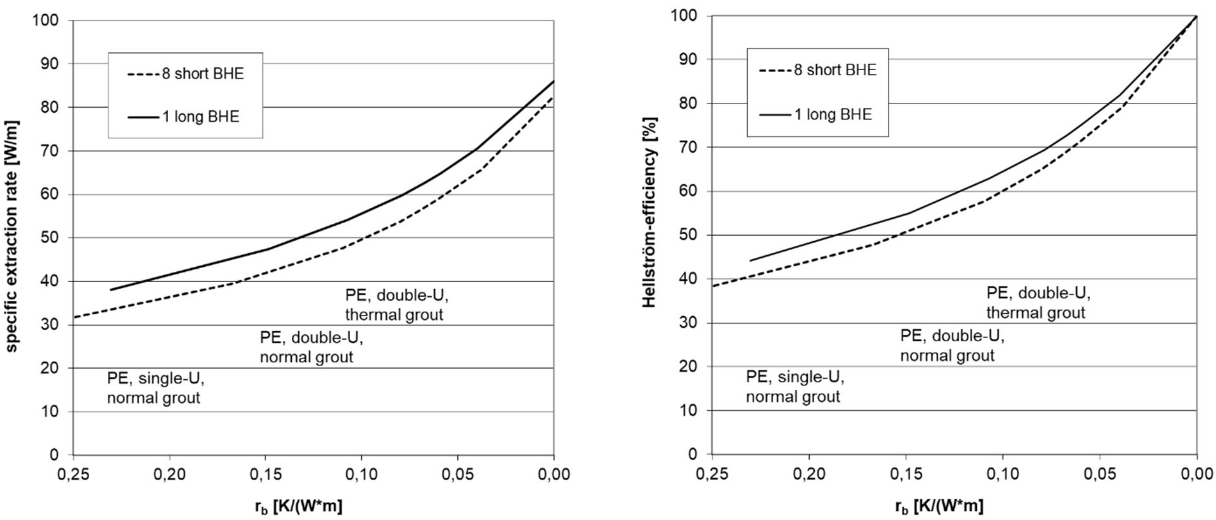


Figure 6: Achievable specific heat rate in a sample GSHP (left) and concept of Hellström-efficiency η_H (right, see text); plotted against r_b-value, areas of typical BHE-types indicated.

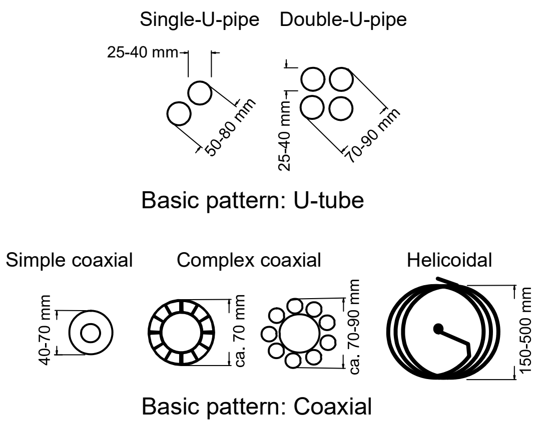


Figure 7: Basic BHE geometry groups

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 8. 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

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 3.3), 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. The energetic and economic expectations have been already stated above.

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

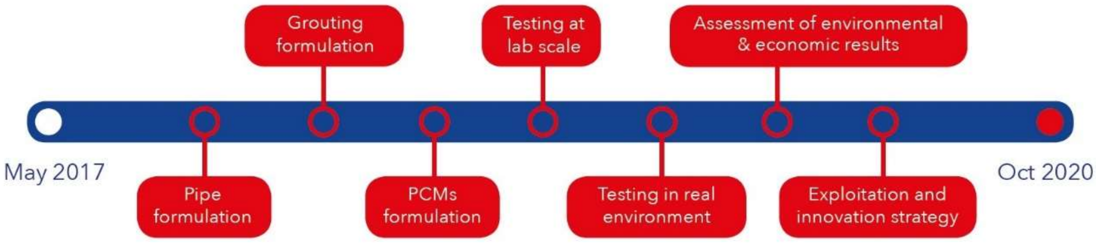


Figure 8: Timeline of project GEOCOND.

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 Scandinavia. 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. PROJECT STATUS AND FIRST RESULTS

The theoretical part of the project is near completion (scheduled for June 2019). This part looked at the various boundary conditions for the pipe and grout materials and the best paths to optimisation. It identified and systematised representative applications, climatic profiles, building and system typologies, and the geological context. Based on this background multicriteria and multiparametric energetic and climatic simulations were started (and are ongoing) to optimise the BHE system in the frame of GSHP and UTES. Other tasks provided documentation on the requirements for piping materials and pipe-/BHE-geometries, as well as for grouting materials, possible soil enhancement, and BHE materials containing PCM to improve storage capacity (UTES). Initial studies on impact and socio-economic environment round this part off. Some details on the simulation and material development are given below; a full account on the simulations is under preparation for a dedicated publication.

5.1 Optimisation of BHE by simulation

An important aspect dealt with in the GEOCOND project is to obtain the optimal design characteristics of the materials that make up the geothermal heat exchangers (pipes, grouting), from a detailed multi-criteria analysis that obtains the optimal values of the different parameters that minimize the value of the thermal resistance.

In this context, a study has been conducted from analytical expressions and tools that model the thermal resistance of the heat exchanger and several scenarios have been simulated in order to unravel the best possible configurations in terms of performance of the installations. The effect of the combination of the different enhancements pursued within the project is evaluated here by means of sensitivity analysis of the main properties of the materials.

The results have been compared with the current state of the art to calculate the impact in economic terms and evaluate the benefits associated to the expected enhancements. In the tested scenarios, it was possible to corroborate that the enhancement of the thermal conductivity of the pipelines and the grouting products in combination may trigger important reduction of the total BHE length required for a certain installation. Those saving could achieve values up to 22 % of the total installation costs.

Moreover, the results have demonstrated that the optimal combination of thermal conductivity for pipes and grouting not always should be the highest possible value but should be in concordance with the thermal characteristics of the ground. In this way, it has been demonstrated that the thermal properties of the grouting products should be adapted to the ground conditions (geological setting) of the place where the geothermal installation will be located.

The obtained results will then be confronted with experimental thermal tests to validate the thermal efficiency of the borehole with the newly developed products and configurations through the development of a state-of-the-art geothermal laboratory that provides controlled and detailed heat injection, gathering in detail the variables involved in the heat exchange process of the borehole heat exchanger.

5.2 Material development

The pipe material development aimed at developing a plastic that has higher thermal conductivity but retains the good properties of PE. In January 2019 first samples of such material were presented to the consortium (Fig. 9), still in small diameter and from the prototype extruders at project partner AIMPLAS. Also, samples of new grouting material exist (e.g. by using carbon-based additives to improve thermal conductivity), and are undergoing test for thermal conductivity and later also for the other parameters required.

6. CONCLUSIONS AND 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 quantity of pipes used to fulfil the same heating and cooling needs enables a decrease of environmental impact.

The theoretical part of the project is well advanced. Suitable materials for plastic pipes with increased thermal conductivity have been developed and tested in the lab. In regard to grouting materials, some promising compositions have been defined and tested. In summer 2019 the first field validation in smaller scale is scheduled at the test site of UPV in Valencia, and ongoing development work will be adjusted by the feedback from the field validation. Full-scale tests in the intended environment are planned in 2020, to verify the efficiency improvements achieved and the practical applicability of the materials on real-world drilling sites.

Figure 9: Pipe material samples with improved thermal conductivity, January 2019.

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