Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Innovative Helicoidal Ground Source Heat Exchanger Coupled with a New Timesaving Installation Technique

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Keywords: ground source heat exchanger, drilling, shallow geothermal system, renewable energy

ABSTRACT

To increase the awareness on sustainable shallow geo-energy solutions the European commission funded the H2020 project „Cheap-GSHPs". The focus of the project are new developments on all components (accessibility of the heat source, ground source heat exchanger, heat pump, software application) of shallow geothermal applications in terms of innovation but also in terms of saving costs. On several real demonstration sites, the new techniques were tested, monitored and evaluated. Under the umbrella of this project, one purpose was the development of vertical helicoidal ground source heat exchangers to fit in boreholes with a diameter of 350 mm. Therefore the design of the spiral collector HELIX© (REHAU AG & Co. KG) was changed in its dimension and in its base material. The new prototype was mounted at selected demonstration sites of the project. In Erlangen, Germany four prototypes were installed down to a depth of 8 m. The boreholes were drilled using the new engineered "enlarged easy-drill technique" which combines hollow auger drilling with a supporting casing in order to strongly reduce the installation time of the ground source heat exchanger and the consecutive grouting process. This paper should evaluate the advantages and barriers of this novel combination of helicoidal ground source heat exchanger and drilling technique.

1. INTRODUCTION

There are many different types of heat exchangers ranging from borehole heat exchangers, which require up to several hundred meters of drilling depth, to horizontal collectors which need many square meters of accessible surface area. A hybrid technology which combines the shallow installation depth of the collector system with the low demand of accessible space is the heat basket or spiral collector. The drilling depth varies from 5-15 m depth, depending on the geometry of such a system and the permission given by the authorities. One huge advantage is the installation above the ground water level. Means, if authorities denied the installation of a ground source heat exchanger (GSHE) using boreholes > 20 m depth there is still the possibility to you use the heat basket system the extract geothermal energy from the ground above the groundwater-bearing formation.

One of the objectives of the Cheap-GSHPs project is to progress the 'heat basket type' GSHE beyond the state of art by installing heat baskets at greater depths. This objective is being pursued through the development of a machine and drilling tool solutions to cope with the large diameters required to accommodate the heat baskets whilst working at the same time on the reduction of heat basket diameters to successfully achieve drilling at greater depths.

Heat baskets are typically installed with dry auger drilling tools attached to an excavator which is usually present on construction sites. Installation depths are limited to 1.5-4.5 m due to the required large drilling diameters of 400-450 mm. The newly developed Easy Drill technique by HYDRA S.R.L. provides boreholes with diameters up to 325 mm in all types of soil. Inspired on the heat basket & helix type of heat exchangers, REHAU has designed and produced some new prototypes of heat basket type GSHE which fit into borehole of smaller diameter (< 350 mm) as needed for the standard Helix© product. The use of a geothermal system is associated with many advantages. One important aspect to consider in the planning and design of geothermal systems is the underground. If we consider the natural temperature profile of the underground, then we can see that the temperature rises as the depth increases. The rate of increase is dependent on the geographical location.

If we consider the upper temperature fluctuation range more precisely down to a depth of 20 m, then we see that the fluctuation margin of seasonal impact decreases as the depth increases. From a depth of around 10 m, the underground temperature can be regarded as constant (Figure 1). In recent years, this finding has also resulted in the use of helical collectors, which are also referred to as spiral collectors, becoming increasingly popular in the near-surface area down to a depth of approx. 5 m. The helicoidal arrangement of the pipe has allowed significant improvements in system performance compared with a conventional surface collector.

Where the cooling demand is more dominant than the heating demand of a building, this typically results in the installation of a shorter geothermal probe system. When a classic double-U probe and the spiral collector are compared, the spiral delivers significantly better performance values, as has been proven scientifically (Zarrella, Capozza, & De Carli, 2013)

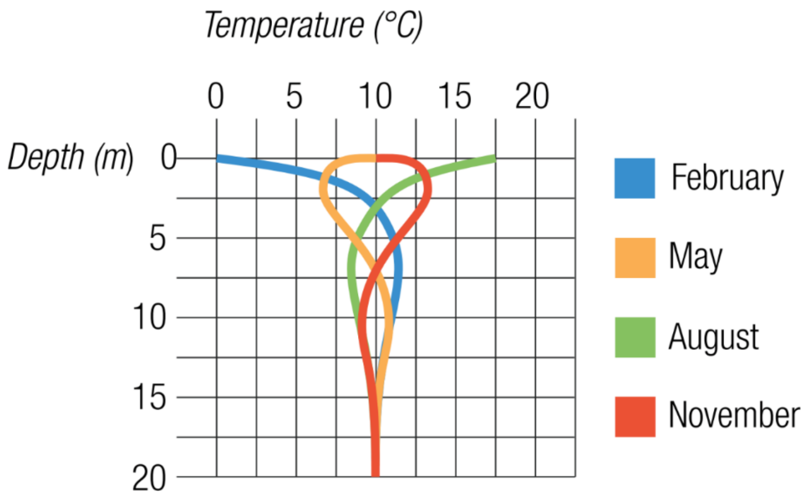

Figure 1: Temperature distribution over the year from 0-20 m depth (REHAU AG+Co, 2011).

2. NEW MATERIALS AND TECHNOLOGIES

2.1 New Material for Innovative Helicoidal Ground Source Heat Exchanger

Plastic materials are frequently used in the manufacture of geothermal products. The reasons for this include the high flexibility and resistance to corrosion properties as well as the low costs. To harness the energy source from the ground, the geothermal systems utilizes mostly single pipe configurations installed permanently underground. Subsequent modification or removal is generally not possible. The materials used must therefore meet certain quality and safety requirements. Directives and standards for the quality assurance, installation and operation of geothermal systems have been compiled for this in recent years in almost all EU Member States. The directives and standards describe a standard pipe as a tube with a standard dimension ratio (SDR) of 11. The SDR value reflects the relationship between the external pipe diameter and the wall thickness of the pipe, and thus allows inference of a specific pressure resistance. An SDR 11 pipe of PE 100 material gives a pressure resistance of PN 16 (PN = nominal pressure). A further quality requirement of checking of the long-term hydro-static pressure is included in almost all directives. This parameter provides a realistic statement of the durability of a plastic pipe under internal pressure. When determining the long-term hydrostatic pressure, the temperature and medium play a critical role. In trials, some of which last several years, it is ultimately also possible to make statements about the aging and durability of the pipes. As the quality requirements have increased in recent years and the protection of ground-water and soil has become increasingly significant, more robust plastic materials in the area of geothermal applications have become the norm for the manufacture of geothermal systems. Today, it is no longer simple PE 100 materials that are used but rather PE 100 RC materials or PE-X materials. The material produced with peroxide crosslinking is identified as PE-Xa material.

2.1.1 Production of the New Pipe Material

Very different equipment and machines are required for the crosslinking compared with the manufacture of PE 100 RC pipes. With peroxide crosslinking, the peroxide and a corresponding stabilizer are mixed before melting the high-molecular polyethylene, and the resulting pellets created are fed into the extruder. The actual crosslinking takes place during the extrusion process at high temperatures (approx. 230 °C) and under high pressure directly in the molten material. The crosslinking process produces a reduced degree of crystallization and a lower density compared with PE 100 material. However, this reduced crystallization is associated with a significant advantage of the material allowing the extruded pipe made of PE-Xa material to be significantly more flexible than a pipe of the same size made of PE 100 or PE 100 RC. To be able to guarantee the properties of the new PE-Xa material, a certain level of crosslinking is required. However, the crosslinking cannot happen at any desired speed within the extrusion process but rather takes time. The production speed compared with a PE 100 material is significantly reduced.

For the new developed helicoidal ground source heat exchanger a cold winding manufacturing process was selected. The process of cold winding is generally used. In this, a plastic pipe with an external diameter of 25 mm in a PE 100 RC material is usually wound around a Coiler or onto a fixing system. As the pipe is cold, winding radii below the minimum bending radius cannot be achieved. Furthermore, the pipe must be fixed so that it remains bent. The pipe is fixed either in a prefabricated grid or in corresponding holding devices. Because it is fixed to a holding sys-tem, the manufacture of the spiral collector here is performed in the original dimensions. Neither the diameter nor the length of the spiral collector can be altered, e.g. for transport. Most spiral collectors are therefore generally between 2 and 3 m long. The flexibility in particular must be seen as an advantage of the manufacturing process. If holding devices with various diameters are available then quick changing between them is possible. Equally advantageous is the fact that the ovality, i.e. the roundness, of the pipe does not change during the winding process due to the crystallized plastic material. All the available joining techniques can therefore be used at any time.

2.1.2 Simulation of the Helicoidal GSHE

For the development of the new GSHE design different pipe lengths were simulated. In Figure 7, the ratio of pressure loss depending on the volume flow rate is shown for 1, 2, 3 and 4 interconnected spiral collectors. The limit of 0.3 bar should not be exceeded as this represents the typical pressure loss for heat basket. In Figure 2 it can be seen that the pipe length should be below 120 m to realize a turbulent flow and thereby a better heat transfer. A specific maximum volume flow rate therefore arises which decreases as the pipe length increases. As a result of the flow speed reduction, the heat transfer within the pipe also decreases, which results in a fall in the extraction performance per meter.

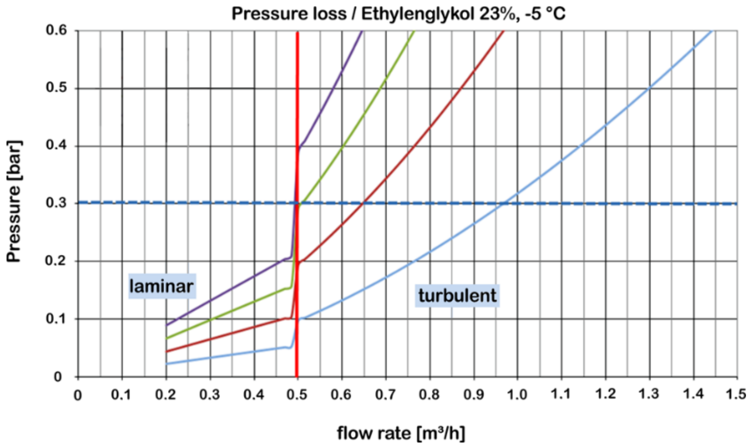

Figure 2: Pressure loss for different pipe lengths (Psyk, De Carli, Emmi, & Zarrella, 2016) .

The geometry of the ground heat exchanger has been modified in terms of external diameter and pitch. Six configurations have been simulated with an inverse numerical approach using CaRM tool (Capozza, Zarrella, & De Carli, 2015; Zarrella, Emmi, & De Carli, 2015; Zarrella & Pasquier, 2015) combining weather data from Venice (Italy) and thermal properties with $\lambda_g = 1.8$ W/(m*K), $\rho_g = 1655$ kg/m³ and $c_g = 1460$ J/(kg*K) where λ_g, ρ_g and c_g are thermal conductivity, density and specific heat capacity. Based on the simulation presented in chapter 5, the following table displays the results of the simulation with 25 x 2.3 mm pipe depending on the achieved diameter of the heat basket. Also integrated are the results of the pressure loss calculations Based on the simulations, a heat basket with 325 mm diameter shows the best performance regarding pressure loss and heat extraction of about 70 W/m depths.

Based on this outcome this geometry was favoured for field tests in Molinella (Italy) (Galgaro et al., 2017) as illustrated in Figures 3 and 4a,b. The pipe, with a total length of 25 m, is multilayered and consists of PE-Xa/ aluminum/ PE material. The cold-winded, 25 × 3.7 mm stable pipe is produced by REHAU AG + CO. The novelty of the new GSHE is the inlet flow manufactured from a co-extruded *RAUTITAN* single helix. A huge advantage is the possibility to extend the spiral just at the drilling site. From a transportation length of 1.0 m the heat basket could be stretched to around 15 m (Figure 3). The diameter of the spiral was around 250 mm in order to allow a proper backfilling process of the heat exchanger and the pitch varies was 600-690 mm. The return flow is a *RAUTITAN* 25 × 3.7 mm monolayer PE pipe with a length of 15 m. The connection between the inlet and return flow is ensured via a compression sleeve joining *RAUTITAN PX* to reach a total pipe length of 40 m. Therefore, also the total installation depth is designed for a borehole depth of 15 m. The installation time was recorded in this test as being 1 min and 38 sec. The installation was realized with a little weight of about 6 kg and no fixation was needed for the installation process due to internal material stability (Figure 4a and 4b).

Figure 3: RAUTITAN stable pipe before the extension process.

Figure 4: a) No need for retaining bands or other fixations. The new 25 × 3.7 mm stable pipe from REHAU AG+Co retains its geometry after the extension process (left). b) The spiral prototype installed within the 'enlarged easy drill' hollow auger segments (right).

2.1.1 Drilling Technique 'Enlarged Easy Drill'

Development basis for a novel technique was the so called 'easy drill technology' of the Italian drilling machine producer HYDRA S.R.L., The clue of this technique consists in employing casings as drilling rods which has been a fundamental basis to develop a new technique within this project called 'enlarged easy drill'. The standard sizes of easy-drill usually ranges from 101 to 152 mm and has been used for years by HYDRA S.R.L. and its customers all around the world, making it a reliable solution in certain kind of drilling jobs including perforation for water wells or the installation of a piezometer.

To achieve the aim of the project the standard easy-drill has been modified to be used with a larger diameter. The enlarged easy-drill is a variation of the traditional one, designed in order to optimize the cost/installation for large diameter GSHE. The new design consists of 1.5 m long tubes with an external diameter of 355.6 mm. On the outer surface of the tube a metal spiral with an external diameter of 450 mm has been welded. Such design avoids the use of water due to the spiral around the tube. Therefore the ground is removed out of the borehole by the augers and not by water/mud recirculation. The lack of water results in a consistent saving in terms of high flow water pumping station and water storage volume of several cubic meters that would normally be required.

The connection between the tubes has been designed with male/female connection sleeves welded on the extremity of each tube. Each pair of sleeves has four keys to transmit the torque and two bolts which guarantee the lock in the axis between the tubes. This particular design results in an improvement in terms of rod handling operation and therefore in terms of time if compared with a traditional thread connections. For large diameters, the action of coupling heavy tubes with a cylindrical thread could be very tricky, whilst with the new design the presence of chamfers on all the edges helps in the coupling operation even though the tube are not perfectly aligned. Another advantage of the new design is that the large clamping system, necessary for unscrewing the threaded tubes, is no longer required and the investment cost of the machine is reduced. Figures 5a and 5b show the sleeves design with keys, bolt and the geometry of the casing with the welded spiral. As illustrated below the inner diameter has been enlarged to 355.6 mm to fit with the new developed GSHE. The overall outer diameter, i.e. external diameter of the metal spiral, turn out to be 450 mm.

Figure 5: a) Manufactured enlarged easy drill segments (left) b) Technical drawing of the hollow auger drilling tools (right). Both figures (Bernini, 2016))

The standard easy drill technique was equipped with an extractable bit. Due to its complexity, the manufacturing process for larger diameter turns out to be an expensive process that would affect the installation cost, together with the fact that the considerable weight of the bit would make the locking and unlocking action difficult. For these reasons, a different solution to keep drilling cost low has been chosen. A drill bit to be lost down at the bottom of the hole has been designed with a low cost manufacturing approach. The unlocking system has been designed to unfasten the bit at the end of the drilling. The drill bit is made of two main triangular sheets of metal welded together to form a cross, then the cross is closed all around by other triangular sheets metal to produce a conical shape. The cost of the bit is approx. 80 € including the welding time. Four fins insure the fastening with the casing. Turning the casing counter clockwise results in the fins exiting from the guide located on the casing and disconnecting the bit from the casing. An overall comparison between the easy drill technique and the new developed enlarged easy drill technique is done in Table 1. The new developed enlarged easy drill technique was used on the project's test sites in Greece (Chaldezos & Karytsas, 2017), Ireland, Spain (Urchueguía et al., 2018) and Germany (Bertermann et al., 2018).

Table 1: Comparison between 'easy drill technique' and 'enlarged easy drill technique' (Bernini, 2016)

	EASY DRILL (inner diameter = 325 mm)	***ENLARGED EASY DRILL*** (*inner diameter = 340 mm*)
Cost of manufacturing	High	Medium-Low
Water requirement for operation	> 1000 dm^3/min	No water required
Optimum depth	< 40 m	< 15 - 18 m
Price	~ 25000 €	~ 10000 €
Type of soil	Unconsolidated material, sedimentary rocks, sand, gravel, clay	Unconsolidated material, soft soil, sand, gravel, clay
Type of bit	Tricone, chevron bit	Simplified chevron bit to lose
Torque required	2000 kg*m	8000 kg*m
Type of casing	Standard drilling casing	Special casing with spiral welded on the outer surface
Connection between casing	Thread connection	Key and bolt connection
Easy to casing coupling	Difficult	Easy
Easy to dismount	Difficult, clamping system required	Easy, unscrew two bolts
Drill bit	Re-usable drill bit	Drill bit to lose

To be able to use this new developed drilling method also the technical properties of the drilling rig had to be changes/adjusted. Especially the fact that you need 6000 kg*s more torque, compared to the standard techniques, makes a new machinery set-up inescapable. The new specification of HYDRA S.R.L.'s drilling machine *Joy 4* made it possible to apply the enlarged easy drill technique. The drilling rig can be seen in Figure 6. The main machine specifications are listed below in Table 2:

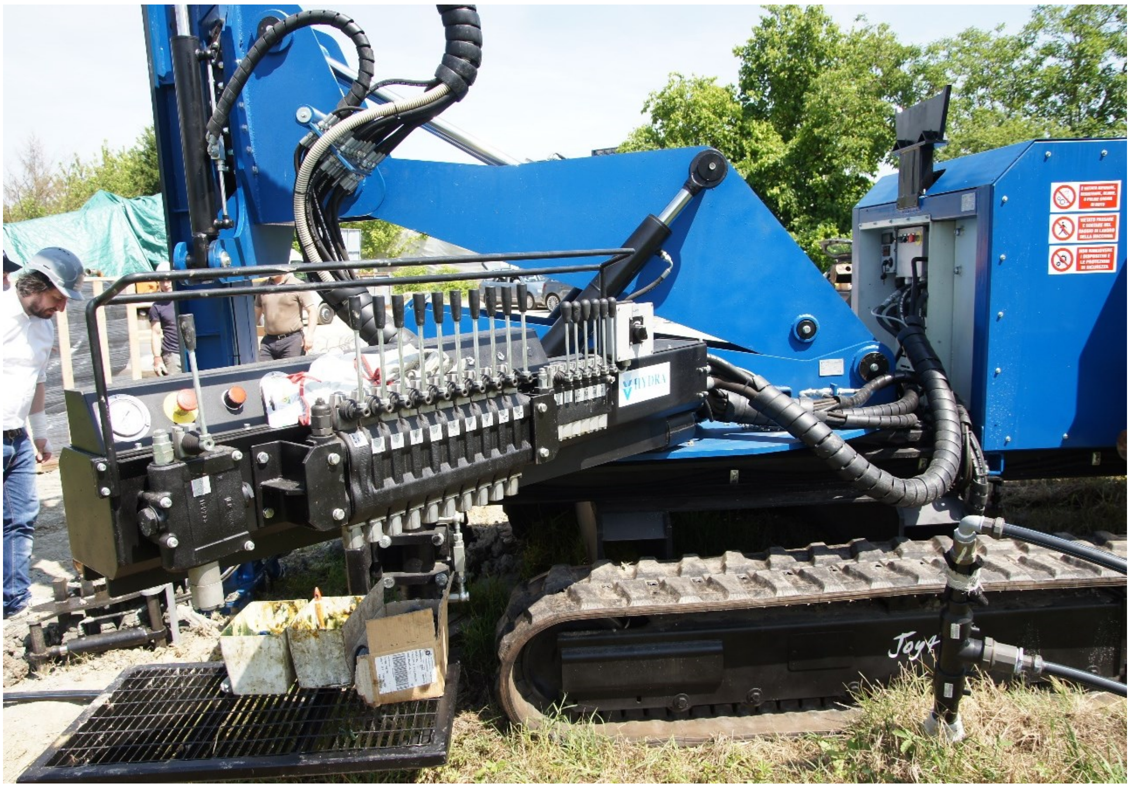

Figure 6: Drilling machine *JOY 4* from HYDRA s.r.l. during the test drillings in Molinella (Italy)

Table 2: Drilling machine *JOY 4* - Specifications (Bernini, 2016)

Machine name	JOY 4
Manufacturer	HYDRA
Power	125 hp
Engine fuel	Diesel
Type of traction	Tracked vehicle
Number of outrigger	4
Mast type	SL 400
Length of the mast	7 m
Pull up - pull down	9 tons
Rotary name	T8000
Rotary torque	8000 kg*m
Tower tilt	+15° until -15°
Winch pull	3000 kg

During the real tests in Molinella (Italy) two boreholes were drilled at a depth of 15 m each (Figure 7a, b). Each drilling operation took 5-8 h to reach the final depth. Drilling time can considerably change according to the type of soil that characterized the region. The drilling costs have been estimated around 70-80 €/m. In the Molinella case (Italy), the stickiness of the clay that stuck on the casings results in some extra time to allow the material to be removed from the borehole. Another observation to point out is that during all the perforation the casing had always to turn in a clockwise direction to prevent the drill bit unlock. Only at the end of the perforation the bit to lose is unfasten by turning the casing counter clockwise. The special mechanism that has been designed permits to unlock the drill bit from the casing by applying a counter clockwise rotation, the drill bit is then left into the ground while the casings are extracted. Another drilling observation is that, with a 7 m mast, time can be saved due to the fact that four casing (i.e. 6 m length casing) can remain always on the mast and therefore the rod handling time is consistently reduced. The investment cost for a *Joy 4* without the necessary drilling tools is in the order of 120000 €. The cost of the drilling equipment depends on the quantity of tubes needed, but the cost can be estimated to be around 1500 €/m.

Figure 7: Enlarged Easy Technique during the drilling at the Molinella (Italy) test site. a) Drilling in more sandy units (left). b) Decoupling of two 'Enlarge Easy Drill' segments after penetrating more plastic units.

CONCLUSION

After several field test of in total seven different types of helicoidal borehole collectors the final prototype for tests at real demonstration sites all over Europe was evaluated. The inlet flow is made of RAUTITAN single helix, cold winded, 25 m pipe length, 25 x 3.7 mm stable pipe, PE-Xa/Al/PE and the return pipe is made of RAUTITAN, 15 m pipe length (25 x 3.7 mm stable pipe, PE-Xa). For this type of GSHE the standard easy drill technique of HYDRA S.r.l. was successfully enlarged up to an inner diameter of 340 mm in order to fit a spiral collector with a diameter of 325 mm. With this combination of drilling techinque and novel GSHE design, four real demonstration sites of the Cheap-GSHPs project were equipped. The geothermal installation at the four different test sites were technically evaluated and their perfomance was compared via a KPI-analyses accessable at the project homepage of Cheap-GSHPs (https://cheap-gshp.eu/). The results developed within the Cheap-GSHPs project were the motive in order to start the H2020 European project GEO4CIVHIC (https://geo4civhic.eu/) where low cost and efficient geothermal systems for retrofitting civil and historical buildings are engineered and tested.

ACKNOWLEDGMENT

Cheap-GSHPs project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 657982. *GEO4CIVHIC* project receives funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 792355.

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