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The GRE GEO Project – Development of Corrosion-Resistant Casing System

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ABSTRACT

Two of the key challenges currently encountered in the geothermal industry are corrosion and scaling. These problems significantly reduce the lifespan of the steel casing systems, causing wellbore integrity issues, which could lead to major environmental contamination. Moreover, the corrosion leads to surface degradation of the casing, causing excessive pressure losses. To prevent major damage, costly workover operations are inevitable, becoming a substantial financial burden and may ultimately jeopardize project economics.

The GEOTHERMICA-funded GRE-GEO project rallies a multinational consortium of geothermal experts to solve these challenges through development of the new glass fiber reinforced epoxy casing system for geothermal applications.

In contrast to conventional systems, Glass Reinforced Epoxy (GRE) casings provide a much-desired alternative, as this material is corrosion resistant, and less prone to scaling. GRE tubulars are already used in highly corrosive oil wells; however, the small inner diameters and large outer diameters of GRE pipes and connector systems significantly limits their application in geothermal wells.

GRE GEO is developing an improved GRE casing system, with large enough inner diameter to be installed in geothermal wells without causing relevant pressure drops, even with the typically higher flow rates. The new system is being designed for completion of new geothermal wells and will also be suitable for workover and modernization of old ones. If required by a well integrity management system, the completion string can be configured with a monitorable annulus. As a result, retrofitted wells may not only gain improved corrosion resistance but also an improved production index, improving the profitability even further.

Additionally, the project is undertaking the establishment of necessary standards & guidelines, adjustment of the well design, as well as preparation of the qualification and safe installation procedures of the GRE casing system. Supplementary, a set of optimized handling tools will be offered and provide a running of GRE casing and tubing. Finally, also the possible advantages of GRE on scale forming are evaluated.

To abide well integrity standards and all safety regulations, the development of a new API- and ISO-aligned GRE-standard for casings will be conducted in parallel with the development of the casing system. During the testing phase of the project, the designed pipes are sent through a variety of verification procedures to re-create real subsurface conditions and monitor GRE-pipe performance. The testing program includes short-term and long-term examination. The project will be finalized with the construction of one or more GRE-cased wells to prove the viability of Glass Fiber Reinforced Epoxy casing systems for geothermal wells.

GRE-GEO promises a corrosion-resistant alternative to conventional steel casings, enabling a decrease in operational risks and cost, at the same time improving the lifespan and long-term flow properties in geothermal heating projects.

This paper covers the most recent advances in wear testing, well integrity, scaling mitigation, and construction of specialized GRE tools.

1. INTRODUCTION

Compared to conventional steel casings, GRE pipes have quite different physical properties. These include different stress behavior, different relation between axial and radial stress(es), and a lower wear susceptibility. As previously mentioned, one key advantage of GRE casings is their complete corrosion resistance and their very smooth surface, that slows the deposition of scales. As the surface doesn´t degrade from corrosion, the roughness increases much slower. With steel wells, the surface gets rougher, as the steel degrades from corrosion and scales. One limiting factor, maybe the only one compared to carbon steel casings, is the influence of changing temperatures on the epoxy resin. This has a profound impact on the properties of the pipes, especially on mechanical strength. Experience and early research have shown that temperatures up to 100 °C are manageable and are no constraint when designing the casing system. This temperature envelope will be sufficient for the target market of GRE GEO: Geothermal heating.

The market for geothermal heating is massive: EU households use 79% of their total final energy use for heating and hot water, according to a 2016 report by the European Commission. In industry, space, and industrial process heating account for 70.6% of total final energy use. Heating and cooling accounts for around half of the EU's energy consumption, ahead of the other end-use sectors, transport, and electricity, amounting to 6,497 TWh. This substantial energy demand is mostly sated with fossil fuels. In 2018, only

21% of the total energy used for heating and cooling came from renewable sources (EUROSTAT, 2020). Considering the excellent geothermal potential in wide parts of Europe, geothermal energy can provide a substantial part of the energy needed for heating and cooling. Not only does geothermal energy provide an economic solution to Europe's dependency on foreign energy imports, but also a decisive leverage for the decarbonization of Europe´s energy market.

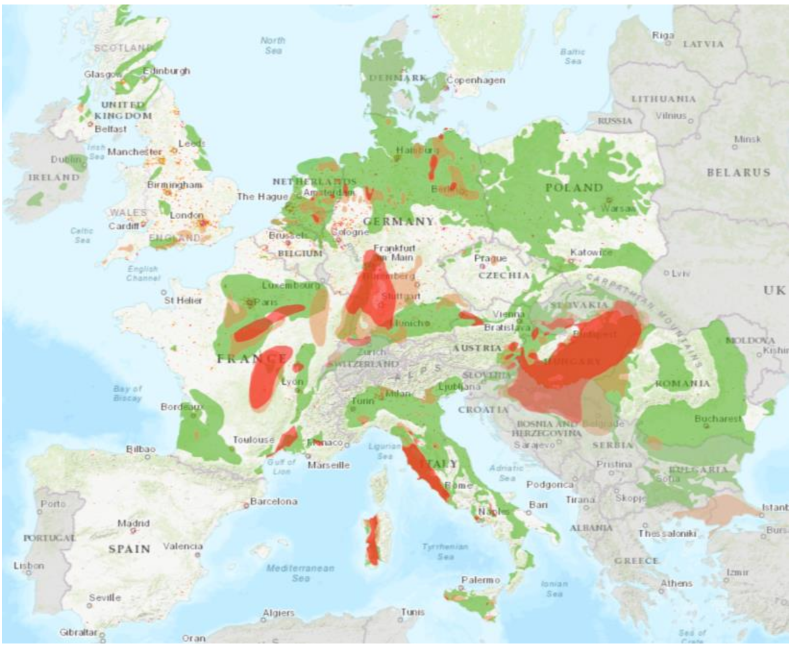

Figure 1: European heat map; green areas are likely to have hydrothermal resources, dark red areas have confirmed temperatures of 90 °C at 2000m, light red 50 °C at 1000m. Adapted from "Pan-European Thermal Atlas", Flensburg, Halmstad and Aalborg Universities, 2018, GeoDH Project, 2014. Copyright Flensburg, Halmstad and Aalborg Universities, 2018, GeoDH Project, 2014

2. DEVELOPMENT OF THE GRE GEO CORROSION RESISTANT CASING SYSTEM

2.1 GRE CASING WEAR: a Qualitative Comparison between traditional and novel composites

The pipes developed so far are currently undergoing testing and verification in the laboratories of the institute for petroleum technology of Technical University Clausthal.

Dynamic internal casing wear is a complex phenomenon due to the number of control variables influencing the wear behaviour. Wear intensity is influenced by individual combinations of service loads (changing force-area distributions), metallurgical properties (material hardness and yield strength) and prevailing tribological mechanisms (surface roughness, friction factors and wear type).

For wear simulation models to be accurate, friction- and wear factors must be experimentally determined by full-scale tests. For this purpose, the design, construction, and application of a full-scale wear test frame to reproduce such friction- and wear factors under field conditions is carried out.

The wear frame is designed to incorporate different casing materials under a range of operational loads and lubrication conditions, and wear scenarios under similar service loads are compared for steel, and fibre-reinforced plastics with glass fibre, as well as carbon fibre. A total of 14 wear tests have been carried out so far for the casing materials under water and mud lubrication conditions (excluding frame calibration and sensitivity runs).

A comparison of test results shows good consistency and agreement with previous experimental studies in terms of friction and wear factors. The wear rate, as depicted by the worn wall thickness, is heavily influenced by the type of fluid and the hardness of the material. A combination of different wear mechanisms is observed in different materials:

For steel casing with water, severe adhesive galling, cutting and polishing patterns are observed. Some material welding is also present.

For steel casing with drilling mud, compressed abrasion and polishing are the primary observed wear patterns.

For glass fibre casing with water, low friction is observed due to contact with the epoxy resin layer. As the contact pressure reduces, wear is dominated mainly by grain removal and 3-body abrasion.

For glass fibre casing with mud, the wear mechanisms remain the same as with water except for inclusion of mud solids and lower surface contact due to the protective mud layer.

For carbon fibre casing, the contact area is pressed and distorted by the tool joint in both water and mud cases. Ploughing and 3-body abrasion are prime wear mechanisms in both cases.

The friction coefficient for steel with water is attributed to a combined friction effect of dry adhesion and ploughing. For mud cases, galling does not take place as it can only occur after breaking through the mud layer, which is continually renewed due to the constant mud flow. Density of the solids plays a very important role here in terms of number of solids conveyed at the contact to hinder galling. Fluid viscosity is also relevant as it increases the retention time of the fluid at the contact surface.

For glass fibre casing, the friction performance exceeds the benchmarks (in terms of worn wall thickness) for steel casing, both with water and with mud (see Fig. 2). On a relative note, glass fibre casings generally have a lower burst and collapse rating as compared to steel casings.

The wear factor for all materials is observed to have an initial peak value in the first hour of contact, and then declines drastically to steady ranges, as seen in Figure 3 and 4. In terms of the peak, decline and steady regions observed in the wear factor charts for 8-hour tests, the total wear period can be divided into the initial, normalization, and steady wear stages. The steady downward range of values also provides an estimate of steady wear over time for a particular drill string tension and revolutions per minute, particularly for scenarios such as drilling and rotation off-bottom.

The projected drill string movement depths are based on the tool joint length L_TJ of 29 in, a drill pipe body length L_DP of 28ft and an axial reciprocation speed ω_Axial of 2 m/hr. This implies casing-tool joint contact every 8.53m of drillpipe in the use-case scenario.

With the inclusion of more steel grades, diameters, and new casing materials (aluminium, harder thermoset resins, glass, or layered composites), the wear frame can be used to develop a comprehensive record of wear factors under different field scenarios, and different wear phases for casing and TJ manufacturing industry.

It is also estimated that under similar wear conditions, most material specimens (steel, glass fibre or carbon fibre) will fail to acquire zero wear factor or ultimate wear depth within the 8-hour test duration. Wear tests can then be either extended to longer periods, or consistent wear data from repeated tests can be extrapolated using wear factors from the steady stage to have a good estimate on long-duration wear.

As of Mid-2022, further tests on various mechanical properties of the GRE casings are being conducted and will be published accordingly.

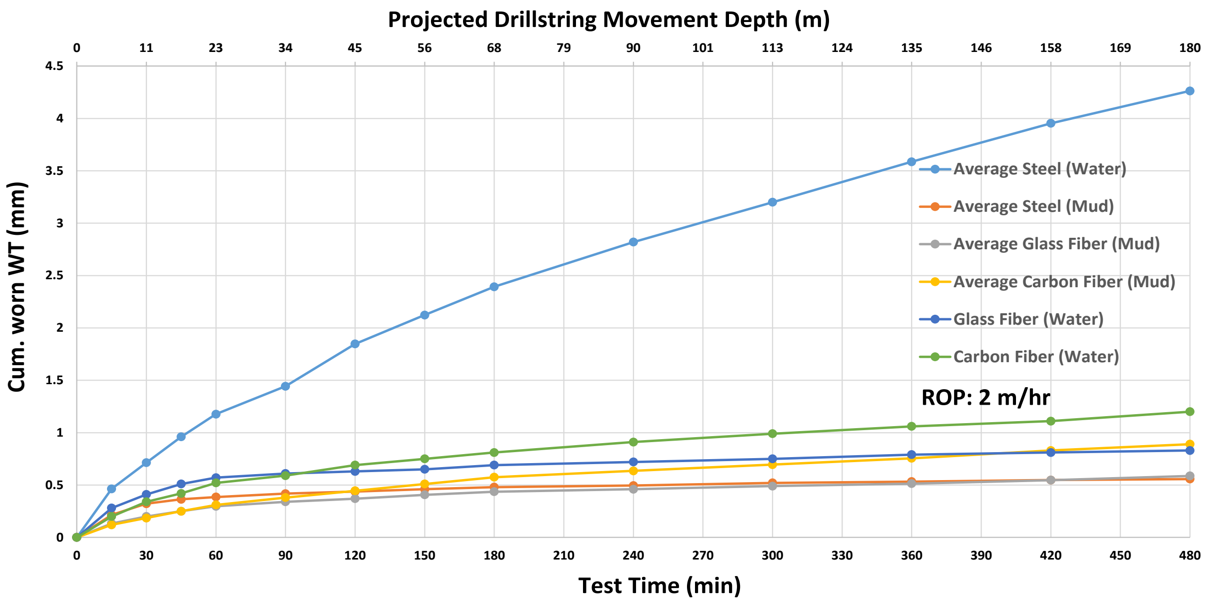

Figure 2: Averaged cumulative worn WT for materials under water and mud conditions

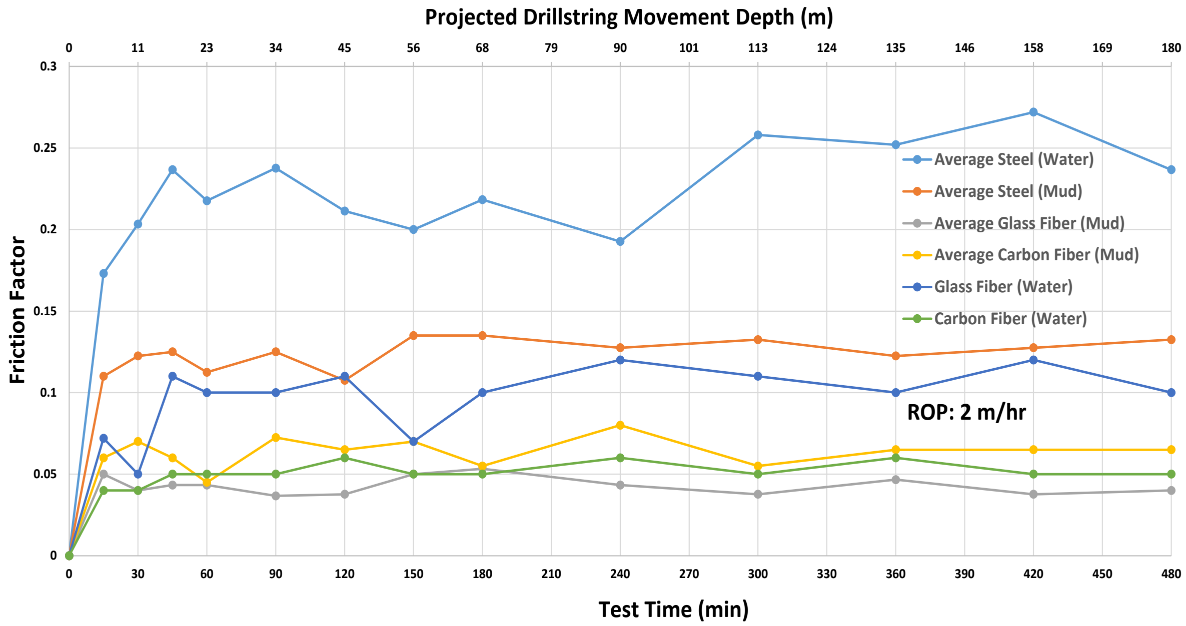

Figure 3: Averaged friction factors for casing contacts under water and mud conditions

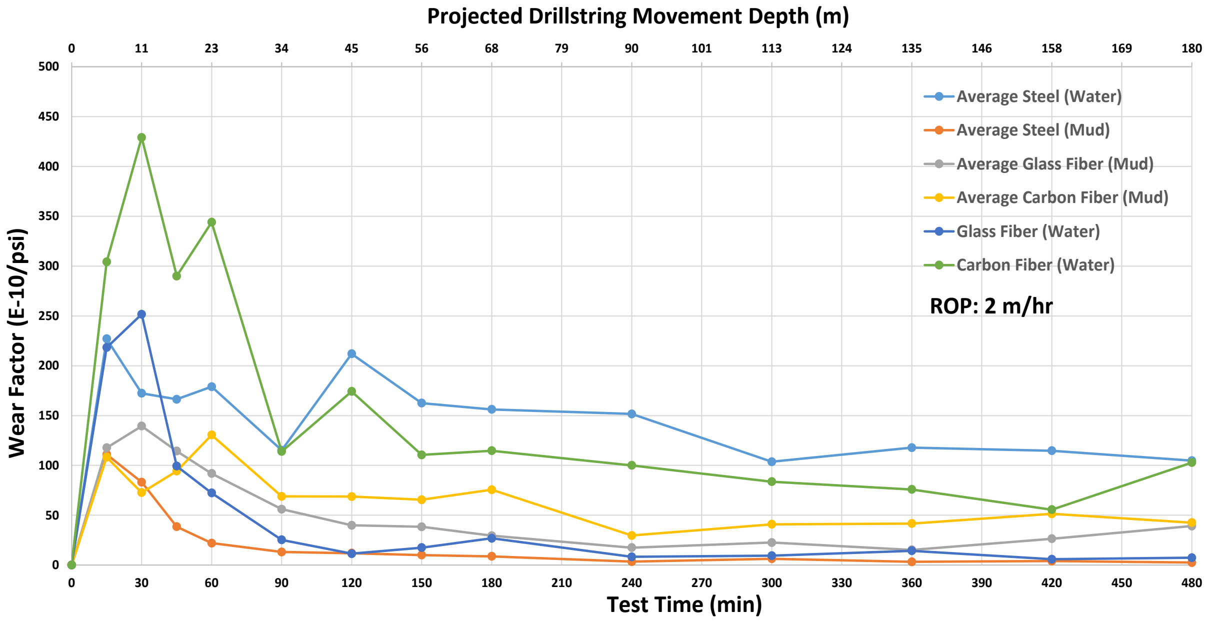

Figure 4: Averaged wear factors for casings under water and mud conditions

2.2 Well integrity for Glass reinforced Epoxy casing based well design

HAZID study

It is advised and often required to conduct a hazard identification and associated risk assessment as part of the general management control system (Well Integrity Management System WIMS). HAZOP, HAZID or BOWTIE methodologies are usually applied to identify these risks and define risk-mitigation measures for each lifecycle of a geothermal well. Although the preparation of such a management control system and associated HAZID studies are the responsibility of the operator it is believed that it is GRE-GEO's responsibility to provide guidance to support the operators with their preparation of the HAZID study and more specifically risks associated with the application of GRE casings in geothermal wells.

In the GRE-GEO project, the HAZID study was initiated at an early stage of the project to support the preparation and selection of the qualification tests required for the materials qualification test program. Also, for the installation tools used during installation the HAZID is a valuable tool to identify GRE specific risks during handling by installation tools that are typically designed for handling of steel casings. HAZID studies for steel-casing based designs that were carried out in the past and that were available in the open literature domain has been used as the basis for the GRE-GEO HAZID study and extended with GRE specific risks. Existing studies often are primarily focused on the installation- and operation phase of the geothermal well lifecycle. Abandoning related risks should also be part of Well Integrity Management System. GRE-GEO has included this phase in the HAZID study as well.

Besides the role of the HAZID study in the selection of the required materials qualification test and development of installation tools it also provides guidance in the guidelines and the development of the industry standard for GRE casings which is one of the main objectives of the GRE-GEO project.

It should be mentioned that the GRE-GEO HAZID study is focused on GRE material specific topics only but still provides valuable information for the operator in preparation of the WIMS for GRE based casing designs.

Compatibility of GRE with geothermal well fluids

Below several examples are provided that are investigated as part of the compatibility studies currently carried out by the GRE-GEO consortium.

Corrosion

One of the main reasons to select GRE for geothermal well casings is the excellent corrosion resistance compared to conventional steel casing. The Dutch State Supervision of Mines (SodM) carried out a study into the integrity of 38 geothermal wells owned by 12 different companies (SodM-2020, SodM2019). Of these 38 wells (of which 8 wells of recent date), 6 wells showed significant wall thickness reduction in the range from 28% to 85%. 15 wells showed a wall thickness reduction of around 25% and 3 wells were found to leak and were closed in. The conclusion of the study was that the anticipated design lifetime of steel-casing based designs cannot be reached and that the probability of leakage was also significantly increased over time. GRE is therefore seen as an attractive alternative to counter corrosion problems related to high salinity production fluids in geothermal wells.

Electrostatic Discharge (ESD)

From the HAZID study, ESD has been flagged as a potential risk as discharge can form an ignition source in the explosion area of the well. Four areas of concern were raised where ESD could form a potential risk:

1. Pumping of drilling fluids during drilling (electrostatic charge generated by fluid flow along the internal and/or external GRE string/casing pipe wall). Both for the producing and for the injector well.
2. Pumping of cement slurry during cementing operation (flow along the internal and/or external GRE string/casing pipe wall). Both for the producing and for the injector well.
3. Flow of production fluids during operation in both the producer well and injection well (Electrostatic charge generated by production fluid flow along the internal GRE pipe wall)
4. Handling of GRE pipe during installation.

An extensive study has been conducted to explore the potential ESD risks identified above. Mitigation actions to minimize the risks were defined and will be part of the guidelines as prepared by the GRE-GEO consortium.

The main findings of the ESD study are:

- Drilling operations: oil based, or water-based drilling fluids were found to be highly conductive and show relaxation times in the order of magnitude of picoseconds. This means that accumulated charge in the liquid almost instantaneously dissipates and therefore will not form an ESD risk. Although not necessary earthing via the drill-string would contribute to dissipation of charge.
- Cementing operations: The same holds for cementing operations. Also cements have a high conductivity and accumulated charge will dissipate almost instantaneously.
- Production: Production fluids in general are also highly conductive fluids (high salinity) and thus have very short relaxation times as well and charge will not accumulate in these fluids. In addition, in combination with downstream earthed conductors (valves etc.) accumulated charge would dissipate via these conductors to earth.
- Verify conductivity of fluids used during installation, cementing and production: As indicated above, typical OBM, WBM, cement slurries and production fluids have a very high conductivity and will not accumulate electrostatic charge in the fluids. It is however recommended to verify the conductivity of the fluids used throughout the lifecycle of the well.
- Handling of GRE during installation: The handling of GRE in the explosion area seems to be a potential risk for ESD. Although these risks are equal to ESD risks created by human bodies, precautions will be required to fulfill the requirements provided by industry standards. Examples are e.g., anti-static coatings/sprays, conductive additives to be added to the resin, relative humidity control at the work area or ionizing the air at the working area.

Chemical Compatibility with geothermal fluids

Throughout the lifecycle of the well, casings will be exposed to:

1. Production water
2. Well intervention fluids (descaling chemicals like HCl, HF)
3. Sulfide Reducing Bacteria (SRB)
4. Associated gasses like CO2, H2S.
5. Exposure to radioisotopes that are present in the production fluids

An extensive literature study has been carried out to investigate the compatibility of GRE with these fluids. Based on long-term experience with GRE being used in several industry applications it can be concluded that in general the chemical compatibility of GRE is good and limitations in terms of exposure concentrations, -temperatures and -times are well defined. Based on this information guidelines will be determined for safe operation of GRE casings in geothermal wells. Where needed exposure testing will be part of the test program.

Wear

Similar as for steel-casings, wear of GRE by for example abrasion during installation and intervention tools (e.g., drill shaft contact or wire line operations) has been identified as a potential mechanism that may affect the well integrity. Wear testing is described in chapter 2.1.

2.3 GRE AND SCALE mitigation

The casing material plays an important role in the adhesion of solid inorganic scales such as carbonates and sulphates. The scale formation process results from the large number of species found in a geothermal fluid and from the complex of possible physical mechanisms involved. Multiple physical and chemical processes are involved, which include mass, momentum, and heat transfer, as well as chemical reactions at the equipment surfaces. Consequently, there are multiple material properties where GRE differs from traditional steel, which are important in the formation of scales. These are:

1. GRE's reduced surface roughness and energy that reduce scale adhesion to the surface
2. GRE's abundance of steel, which reduces deposition of e.g. dissolved Pb, As and Sb ions with the less noble elemental iron of a steel casing
3. corrosion resistance of the GRE reducing the need for corrosion inhibitors that potentially can accelerate scale formation

GRE can outperform traditional steel on all these aspects, making it a material less prone to scale formation.

First indicative results with the geochemical software ORCHESTRA© suggest that GRE's reduced scale adhesion results in an overall reduction in scaling. This means that a larger effective inner diameter can be maintained resulting in better well performance. While the overall impact of the reduced scale adhesion is positive, the reduced extraction of scales from the brine can lead to a different brine chemistry in the downstream direction.

More information on scaling and the role of GRE can be found in De With et al. (2022).

2.4 Pilot Well construction

Ultimately, it is planned to demonstrate the developed product in a relevant environment (e.g. demonstration/pilot well). The minimum goal is to achieve a run-in borehole operation, and to demonstrate the suitability of the GRE piping, as well as its handling system, for market acceptance. Depending on the requirements of the end-user a test scenario is developed. The well design is determined together with corresponding GRE-pipes and coupling system. According to the design outcome the piping is produced and supplied for demonstration. In the current phase the consortium is looking for potential partners to enable a relevant practical field test.

Prerequisites for the successful demonstration are the availability of, for instance, the fit for purpose handling tools including a handling tong. Therefore, a market research of potential handling tools is performed, and the next step will be to perform tests, that prove the compatibility of these tools with the GRE pipe product. In addition, a concept for an advanced handling tong will be developed and finally a prototype, for practical testing, shall be produced. Currently, the most promising out of four developed concepts is evaluated for further deployment.

Other prerequisites are for example the definition of the installation process, which will be done parallel to development and/or testing of handling tools and handling tong. Also, the testing of the GRE pipe and the associated draft code, which are presented in other chapters of this paper, are of major importance for the practical demonstration. Finally, training of the crew together with an external partner who is willing to test the product is accounted for. Alternatively, the construction of the pilot well will be done at the site of DrillTec GUT GmbH in Deggendorf.

3. CONCLUSIONS

GRE GEO provides an answer to crucial challenges of geothermal energy: corrosion and scaling. These issues have been often encountered in the North German Basin and similar reservoirs in the Netherlands and Belgium. These reservoirs are close to industrial and population centres. The immunity of Glass Fibre Reinforced Epoxy (GRE) casings to corrosion and pitting will enable the geothermal energy industry to develop previously challenging and uneconomical reservoirs for geothermal heating projects.

The wear test described in chapter 2.1 have shown the strong performance of the GRE material, even compared to steel. Over the course of 2022, extensive testing, and verification of the mechanical properties of GRE will further prove the capabilities of the GRE GEO casing system.

Chapter 2.2 described the first results of the HAZID study. The study is conducted with the aim to identify and understand any material-inherent risks as early as possible. Results from the HAZID, besides their implementation in the GRE GEO project itself, will provide valuable information for the operator in preparation of the WIMS for GRE based casing designs. Another key aspect of the research of this working package is the compatibility of the GRE material with geothermal well fluids. Early in the project, ESD was identified as a potential risk, as the discharge can form an ignition source in explosion hazardous areas. Research has shown, that ESD is not a substantial risk, when working with highly conductive liquids (most OBM, WBM, cement). It is recommended to verify the conductivity of the liquid. Special care must be devoted to handling of GRE during installation. GRE created ESD risks comparable to the risks created by human bodies.

Chemical compatibility was also researched. Literature research showed good chemical compatibility of GRE. Limitations are clearly defined and based on decades of experience in several industry applications.

Chapter 2.4 discussed the prerequisites of the pilot well construction. The GRE GEO project will be finalized by the construction of a pilot well, to prove the viability and market readiness of the casing system. Some of the prerequisites are fit-for-purpose handling tools, guidelines on the installation process, and trained crews. These things will be accounted for in future working packages.

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Figure 1. European heat map; green areas are likely to have hydrothermal resources, dark red areas have confirmed temperatures of 90 °C at 2000m, light red 50 °C at 1000m. Adapted from "Pan-European Thermal Atlas", Flensburg, Halmstad and Aalborg Universities, 2018, GeoDH Project, 2014. Copyright Flensburg, Halmstad and Aalborg Universities, 2018, GeoDH Project 2014

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