Gas, Corrosion, Scaling: New Concepts for the Central Challenges of Geothermal Energy

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Abstract

The highly corrosive environments met in geothermal wells put significant limits on the wide-scale utilization of geothermal resources. Gec-co, one of Germany´s leading engineering companies for geothermal energy projects, is developing innovative new concepts – including a new, jointly developed, glass-reinforced casing system (GRE) and formation gas separation and reinjection - to manage the issues caused by high salinity and gas content, thereby enabling the safe, environmentally friendly, and economical utilization of previously challenging reservoirs.
Corrosion and scaling are a significant challenge in traditional steel casing and tubing systems. Even in high salinity reservoirs, due to its low price, carbon steel remains the material of choice for the casing and most parts of the geothermal plant. Noncorrosive alloys, such as stainless steels, nickel alloys, and titanium are prohibitively expensive. Scaling occurring during operations does not only have a detrimental effect on surface and subsurface equipment, but also leads to environmental safety concerns, as scales often contain normally occurring radioactive materials (NORM). Conventional countermeasures such as a high corrosion allowance or the addition of inhibitors have a limited effectiveness and are often associated with high OPEX.
A cost-effective, non-corrosive alternative to steel is glass-reinforced epoxy (GRE). As part of the Geothermica-funded GRE GEO project, Gec-co and her partners are developing a GRE casing system for geothermal wells. So far, large-diameter pipes for this application have not been available. GRE GEO will develop these pipes, including extensive testing, the drafting of an API-aligned standard for GRE casing systems and the construction of demonstration wells. The preliminary testing has yielded results exceeding the expectations. These and further results will be introduced and discussed in detail as the project progresses.
Alongside high salinity, a high gas-water-ratio (GWR) is a central challenge in many reservoirs (North-German-Basin, Rhine valley, Belgium and the Netherlands). Large quantities of various gases, such as CO2, methane and nitrogen are dissolved in the water. The conventional approach is to keep as much gas as possible dissolved in the water, requiring an operating pressure above the bubble point pressure within the geothermal power plant. This approach reduces the plant efficiency, is very cost intensive, as most parts of the plant must be rated for the high-pressure requirements and reduces plant availability, as unplanned repairs are frequent and scaling still occurs. Despite the countermeasures, the formation of gas within the plant cannot be avoided entirely.
Gec-co has developed an alternative solution to this problem, called Formation Gas Separation. The gas is separated from the water at the surface, before entering the geothermal power plant. The high-pressure thermal water is degassed in a controlled environment within a gas separator. The low-pressure thermal water yields its heat within the power plant and goes to the injection well. Downhole, the gas is mixed with the thermal water. A lower operating pressure within the plant allows the utilization of much thinner pipes, as the pressure difference is lower. This brings an increase in plant efficiency, lower costs, and higher plant availability. Another advantage is the substantial reduction of scaling. Gec-co has utilized this process in a 35 MW geothermal heating plant in Belgium to great success. The key features and advantages of Gec-co´s solutions shall be discussed in this paper.

1. Introduction
1.1 The Market for Geothermal Heating and Cooling in Europe

The market for geothermal heating is massive: EU households use 79% of their total final energy use for water 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 provides geothermal energy an economical solution to Europe's dependency on foreign energy imports, but also a decisive leverage for the decarbonization of Europe´s energy markets.

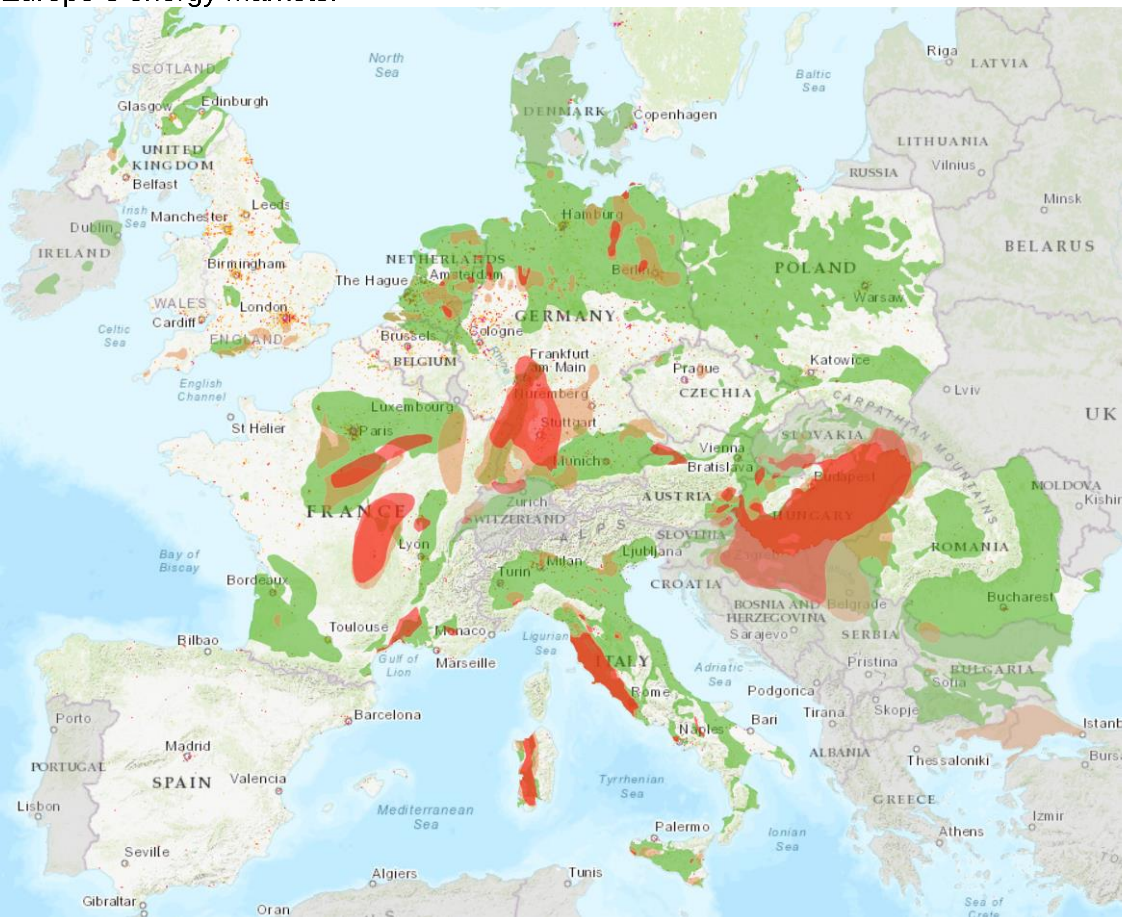

Figure 1: Pan-European Thermal Atlas, green areas are likely to have hydrothermal resources, dark red areas have confirmed temperatures of 90 °C at 2000m, light red 50 °C at 1000m

1.2 Challenges of Geothermal Energy Projects

From an economical point of view, geothermal heating projects are limited by two key challenges: First, the reservoir conditions determine the overall economics of the project, yet they cannot be reliably predicted. The reservoir conditions also have a substantial influence on the initial investments for the wells and the necessary planning time of three to five years (in Germany). Second, when only producing heat, the local demand must be considered. Some countries have extensive experience with district heating, especially in Northern and Eastern Europe (50 to 90% of homes are connected to mostly fossil-based district heating [European Commission, 2016]). When conducting a project feasibility study, the empirical data on local heating technologies is often lacking. In-Depth knowledge on the age, capacity and units is vital to estimate the economic viability of a geothermal heating project. Germany has constant monitoring schemes in place, that collect this data.

These challenges are offset by the previously mentioned advantages and long-term economic benefits. Compared to conventional, fossil-based energy sources, where initial investments and operating expenses have a 50:50 ratio, geothermal energy projects have high initial costs, and low operating costs, resulting in only 20% operating expenses. The initial costs are influenced by multiple factors. Some of them cannot be influenced. Geological conditions, like drilling costs, and production and injection rates for the wells, can diverge from the predicted value. These, and other, risks can be reduced or managed by a skilled and experienced project developer.

1.3 Managing the risks of geothermal heating projects

One substantial advantage of geothermal heating projects is the lower minimal temperature requirement. 80 to 100 °C are adequate for economical operations. For electrical power from geothermal energy, temperatures above 160 °C are necessary. Small deviations from the expected temperature often mean the end for a project, whereas geothermal heating projects are far less sensitive to unexpected deviations in reservoir temperature.

With lower minimal temperatures, far more locations have the potential for geothermal heating projects. Lower drilling depths also lead to a significant decrease in drilling costs. The likelihood of a successful well largely depends in the quality of geological exploration in the area. In recent years, the overall data quality and projection quality has increased. Geothermal energy projects in Europe also profit from the exploration efforts of past decades. Regions with a high geothermal potential, like the North German basin, Rhine valley, and the Netherlands also were subject to extensive oil and gas operations. Experience from these operations and a quickly growing number of geothermal energy projects, significantly reduce the risk of “dry” wells. Reducing the risk of unsuccessful wells also improves the financing conditions for new projects. This will enable more cost-sensitive operators, like municipalities, to finance their geothermal energy projects.

1.4 Meeting technical challenges

Operational experience has proven, that scaling and corrosion within the wells and surface installations are the key technical challenges within geothermal energy projects. The reservoirs, that are attractive for heating projects (NGB, Rhine valley, Netherlands), feature brines with high salinity and high gas content. This requires careful considerations for process design, material choice, and operation. Yet, despite the best of efforts, these challenges have a profound impact on project economics. The conventional approach to these issues is the utilization of steel alloys with higher corrosion resistance, high operational pressure, to keep the gas in solution, and large corrosion allowances. All these measures come with a substantial cost. Steel alloys with a sufficient corrosion resistance are expensive and building surface installations with a PN40 pressure rating is very expensive. These costs are in many cases too high for geothermal heating projects. Only geothermal power projects produce the necessary profits to offset these expenses.

Gec-co is developing a solution to these challenges with two flagship projects: GRE-GEO and the Beerse heating plant in Belgium. GRE-GEO will provide a casing system, made from corrosion-proof glassfiber reinforced epoxy, that is a long-term and low-cost casing system, ideal for geothermal heating projects. The Beerse plant is the first to utilize gec-cos proprietary formation gas separation and reinjection process, allowing the utilization of this otherwise uneconomical reservoir.

2. GRE GEO – The corrosion-proof Casing System

The construction of production and injection wells is by far the most cost intensive part of a geothermal energy plant, and the most critical when it comes to failures during construction, operations, and workover. An inoperable well can end a project, as the expenses required for a sidetrack or replacement well exceed the financial resources of most projects. During operation, scaling and corrosion can lead to problems with wellbore integrity. To keep costs acceptable, most geothermal wells are cased with carbon steel pipes. These have a minimal resistance to corrosion. Moreover, the corrosion leads to a surface degradation of the pipe, increasing pressure losses. To prevent major damage, the continuous injection of inhibitors and workover operations like reaming and acid jobs must be conducted frequently to remove and control scales, becoming a substantial financial burden.

The Geothermica-funded GRE-GEO project rallies a multinational consortium of experts in pipe manufacturing, drilling engineering, well design, research, and geothermal and chemical engineering fields to solve these challenges through development of the new glass fiber reinforced epoxy casing system for geothermal applications.

2.1 Glass Reinforced Epoxy – Production and Properties

GRE is a composite material, made from two components: Glassfiber and a filler, in our case epoxy. To produce a GRE pipe, multiple endless glassfiber strings are wetted in epoxy. In a highly automated process, the fibers are applied, or wound, on the mandrel, a precisely machined cylinder with a known outer diameter. These fibers are applied to the mandrel until the target wall thickness is reached. Future Pipe Industries, a consortium member of the GRE GEO project, has decades of experience producing composite pipes for a wide variety of applications. During the construction of the pipe, winding angles of the fibers, wall thickness, properties of the specific glassfiber and epoxy, and the ratio of fiber to epoxy can be used to precisely fit the mechanical properties of the pipe to the intended use.

Compared to conventional steel casings, GRE pipes have quite different physical properties. These include different stress behavior, different relation between axial stress and radial stress(es), and a lower wear susceptibility. As previously mentioned, on 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 smoothness doesn´t change over the lifetime of the well. 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 no constraint when designing the casing system. This temperature envelope will be sufficient for most geothermal heating projects.

2.2 Experience with GRE pipes in well construction

GRE is far from a novel material in well design, as corrosion is often an issue in oil and gas wells, caused by high salinity of the oil byproducts or high H2S and CO2 contents in the associated petroleum gases. Common solutions are GRE or Polyethylene (PE) lined steel tubing. Lining a regular steel casing with GRE is not a preferred option for geothermal wells, as it is very difficult to keep the joints sealed over the lifetime off the well. Corrosion will still occur, as brine gets in contact with the steel casing through joints or damage in the liner. Full GRE casings have seen plenty of use in the oil industry as well. Well construction is not much different than conventional completions. Special attention must be paid to cementing, as proper mud removal is essential to guarantee a good bond between the cement and the very smooth surface on the GRE casings. At the rig, the GRE casings must be handled with greater care, as the torque values are lower than steel. From experience, the time per joint is roughly equal, if slightly higher, compared to steel. Completing a well with GRE casings is not more complex, difficult, or expensive than a conventional completion, just slightly different.

2.3 Goals and Timeframe of GRE GEO

GRE casings are already in regular commercial use in the oil industry. The reason GRE has not been in used for geothermal wells, are the different legislations and requirements for casing diameters. Geothermal wells need larger casing diameters, to enable very high production rates. So far, large-diameter GRE casings have not been tested and verified to the standards necessary for geothermal use. This is the missing link GRE GEO aims to fill. Thus, the main objective of GRE GEO is to develop a cost-effective glass-fiber reinforced epoxy casing system suited for geothermal heating projects with a relatively large inside diameter and smaller outside diameter. The pipe coupling is especially important, as the diameter of the coupling should be kept as small as possible to allow for large inner diameters and smaller hole sizes. As the GRE technology is already well understood, GRE GEO will focus on the full-scale commercialization of GRE casings for geothermal wells. To achieve this, the project focusses on the establishment of necessary guidelines on well design, qualification of service companies and safe installation procedures. To abide by well integrity standards and all safety regulations, the development a new API- and ISO-aligned standard for GRE casings will be conducted in parallel. The pipes will be sent through a variety of verification procedures to re-create real subsurface conditions and monitor GRE-pipe performance. This will include short- and long-term testing of different load scenarios, to guarantee certain parameters of the casings, like yield and collapse pressure.

The project will be finalized with the construction of one or more GRE-cased wells, which will prove the technical viability of glassfiber reinforced epoxy casing systems in the geothermal market. At the end of the project, by 2023, GRE casing systems can be deployed commercially. According to corrosion problems with traditional steel casings reported by end-users, the new casing system GRE-GEO would meet a-priori the requirements of the most interesting low-enthalpy markets in Europe: the Molasse Basin, Jura, Permian and the Lower Cretaceous, which has a great similarity to the North German Basin.

3 Project Experience: Geothermal Heating in Belgium

A corrosion-proof well is only one part of gec-cos geothermal heating concept. The formation gas separation and reinjection process was first utilized for an industrial customer in Belgium. A chemical producer required 35 MW of process heat, equivalent to 38,000 homes. The goal of the project was to supply zero-carbon heat and cooling for the entire site. The well design was quite standard, with a doublet with a depth of 2500 m, a production rate of 90 L/s and a corrosion-resistant design adequate for the high salinity. The production temperature reached 85 °C, ideal for GRE pipes.

The key challenge of the project was the very high gas content of the brine. 1 m3 of brine contained 1.5 m3 of formation gas, made up from CO2, methane, and nitrogen. Building the plant with a sufficient pressure rating to keep the brine above the bubble point pressure with a PN40 rating was prohibitively expensive, and thus would have meant the end for the project.

This resulted in the birth of formation gas reinjection. In the first process step, the formation gas is separated in a specialized gas separator. This idea was first deployed in the Netherlands, where formation gas ratios are high, and the gas is often combustible due to a sufficient methane content. In Belgium, this is not possible, due to regulations, and the customer demanded a zero-carbon solution. Thus, reinjecting the gas into the reservoir was the only solution.

Reinjection the gas into the reservoir must be done with careful consideration, as doing so in an uncontrolled way can damage surface installations and the reservoir itself. For safe operations, the gas must be fully dissolved in the brine when entering the reservoir. Multiphase flow should be kept to an absolute minimum.

3.1 Solubility of Gases in Liquids

For ideal gases, Henry´s law states that the amount of dissolved gas in a liquid is proportional to its partial pressure above the liquid. For a simple reinjection solution, one might simply reinject the gas at the wellhead of the injection well with a sufficiently high pressure. However, multiple factors make this “easy” solution impossible. Henry´s law is only applicable to ideal gases, normal temperatures, and relatively low pressures. The formation gas is a mixture of different gases, with changing fractions. The temperature, or more accurate, the specific enthalpy, of the brine is high, same as the salinity. This decreases the solubility of gases in the brine. Even with numerical simulations, the process conditions cannot be determined reliable enough to enable the stable operation of a surface injection.

Instead of injection the gas at the surface, Gec-co developed a downhole mixing unit. The downhole mixer is mounted deep within the well. The gas pressure is increased at the surface, from around 16 to 60 bar, and pumped through coiled tubing to the downhole mixer, where the gas is mixed with the brine. To avoid condensation of the gas, the temperature is kept above the critical temperature of the formation gas. Due to the hydrostatic pressure of the brine and the high pressure of the gas, process conditions are much more stable, and a safe operation of the plant is possible. Multiphase flow is kept to a minimum. As a backup, gec-cos installation still features the option to inject gas at the surface. During normal operations the downhole mixer is used. The design of the mixer, as well as injection depth will be modified project-by-project and can be easily adjusted to different gas compositions and pressures.

3.2 Advantages of Formation Gas Reinjection

As previously mentioned, separating the gas in a controlled environment allows for a lower pressure rating. Building the plant with a PN25 pressure rating instead of a PN40 is substantially cheaper. Also, a PN25 pressure rating will allow the use of GRE piping in the surface installations. GRE pipes are much cheaper than the highly alloyed steels with an equal corrosion resistance. The corrosion-resistance of GRE pipes will also reduce the operating costs of the plant.

Separating the gas at the beginning of the plant also has a profound impact on scaling. The amount of scales falling out of solution are largely dependent on the pH-value of the brine. When the gas leaves the brine in the separator, the pH-value sharply decreases, as CO2 leaves the brine. This causes a significant percentage of the dissolved salts to fall out of solution. As most of the scaling will occur in a highly controlled environment within the separator, this is not an issue and another key advantage of gec-cos formation gas reinjection process. In a conventional plant, even when using inhibitors, scaling occurs uncontrolled in the entire process, especially in the heat exchangers and bends in the piping. With formation gas reinjection, scaling will mostly occur in the separator, where the scales can be removed easily. This makes operating the plant significantly easier and reduces operating costs, as complex cleaning operations for the heat exchangers and other process equipment can be conducted less frequent.

4. Economics

Giving economical estimations for individual projects is difficult, as many factors influence the final costs. For GRE casing systems, GRE-GEO will give an accurate estimate, as the construction of multiple GRE-cased test wells is part of the project. Yet, we can already assume equal or lower lifecycle costs for GRE well compared to a conventional steel-cased well. The material cost is equal to carbon steel and construction is marginally more time-intensive, as GRE casings require more careful handling, resulting in longer times per casing joint. Potentially higher initial costs are easily offset by the low operating costs of a GRE well. Corrosion and scaling are reduced, pressure losses are lower, all resulting in lower operating costs.

The economic benefits of formation gas reinjection also depend on a wide variety of factors. The cost-savings from the lower pressure rating might be offset by the necessity to buy and operate the gas compressors. A problem encountered in the heating project was the lack of suitable compressors. The required capacity was right in between mid-volume and high-volume standard compressors, requiring a purpose-build compressor with a higher price tag. As this heating plant was the first project of its kind, compressor prices will come down with an increase in demand. Generally, formation gas reinjection will start to have cheaper lifecycle costs than a conventional plant, as formation gas ratios and salinity increase. This is the case for wide variety of reservoirs. In Europe, the North German Basin, the Rhine valley, Belgium, and the Netherlands all have reservoirs with high salinity, high formation gas content and the right temperatures for large-scale geothermal heating and cooling.

Generally, heating concepts require large customers with a stable heat demand of 10 MW to guarantee a stable return on investment over 20 – 30 years. These customers can be industrial companies with a demand for process heat, greenhouses, industrial parks, hospitals, and public baths. Customers from the public sector usually need more support to manage and finance a geothermal heating project yet combining industrial customers with district heating for residential homes is ideal to reach maximum utilization of the available plant capacity. The different usage profiles of industry and district heating allow an optimal management of temperature needs, heat volume, and load profiles. This also helps to diversify the income sources. Cascading or sequential use is the key to maximum utilization of the available heat. Process and district heating need the highest temperatures. Afterwards, the temperature may be sufficient for greenhouses or public baths. The remaining heat can be further extracted by customers with very low temperature requirements, for example fish farms.

5. Conclusion

With the combination of a GRE cased, corrosion-free well and the formation gas reinjection process, gec-co has developed the “missing link” to the decarbonization of Europe´s energy markets. The EU-funded GRE-GEO project is well underway and scheduled to begin construction on the first GRE-cased test wells in 2023. The formation gas reinjection process has been deployed in the commercial Beerse project with great success. With increasing prices for fossil fuels and CO2 certificates, private enterprises and the public sector must move quickly to decarbonize their heating. The technologies presented in this paper allow the wide-scale utilization of previously uneconomical reservoirs for heat production close to the industrial and population centers of Germany, the Netherlands, and the Benelux countries.

6. Sources

EUROPEAN COMMISSION, Directorate-General for Energy Directorate C. 2: Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables), September 2016

EUROSTAT: Renewable energy for heating and cooling. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200211-1, Date of publication: 11.02.2020

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