GeoWell - Innovative Materials and Designs for Long-life High-temperature Geothermal Wells

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Abstract

The GeoWell research project is funded through the EC-Horizon 2020 programme addressing various aspects of new and enhanced technology for the design and operation of high-temperature geothermal wells. These include cement slurry design, casing material selection, coupling of casings, downhole temperature and strain measurements in real time using fibre optic technologies, as well as novel methods for risk assessment with respect to well planning, design and operation of geothermal wells.

The research is focused on both conventional geothermal production wells and deeper wells, where the pressure is as high as 150 bar and temperatures can exceed 400 °C. The technologies under development and material candidates are tested under simulated conditions in laboratories and partly in-situ in existing geothermal environment.

Introduction

Geothermal energy is a promising source to significantly contribute to the renewable energy mix in a long-term perspective. Multinational geothermal research initiatives have been growing considerably over the past few years. To exploit the full potential of geothermal energy for heating and cooling, as well as for generating electricity, the European Commission (EC) supports several research and innovation projects within the Horizon 2020 programme (H2020). One of these projects is GeoWell a three-year project that started in February 2016 with a total budget of € 4.7 million.

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Participants are the research institutions ÍSOR in Iceland (project coordinator), IRIS in Norway, GFZ in Germany, TNO in the Netherlands and BRGM in France, and the industrial companies Statoil in Norway, HS Orka in Iceland and Akiet in the Netherlands.

Concept of the GeoWell Project

The GeoWell project addresses important bottlenecks in geothermal development, like high investment and maintenance costs by developing innovative materials and designs that are superior to the state of the art concepts. The aim is to significantly enhance the current technology position of constructing and operating a geothermal well. The results are expected to make a substantial contribution to the promotion of geothermal energy in Europe and beyond.

The project aims to develop reliable, economical and environmentally friendly technologies for the design, completion and monitoring of high-temperature geothermal wells with the intent to expedite the development of geothermal exploitation globally. GeoWell will addresses relevant steps in the geothermal well construction process to enhance the lifetime of high-temperature geothermal wells. These include novel cement properties and new cementing technologies, novel casing materials and material combination (e. g. internal cladding) and flexible coupling of casings to minimize thermo-mechanical loadings.

Fibre optic cable technology and applications are being developed to measure in real-time downhole temperature and strain to monitor well integrity along with methods for risk assessment regarding the well planning phase and operation of high-temperature geothermal wells. These highlights of the Geowell project will enhance the well construction process and operations of geothermal wells, especially targeting well integrity improvement.

To assure the quality of the approach and the final results of the project, the research is focused on both conventional production wells and deeper wells, where the pressure is as high as 150 bar and temperatures exceed 400 °C. The developed technologies and material candidates are tested under simulated conditions in laboratories and partly in-situ in existing geothermal environment.

Cementing of Casing Strings

The objective is to develop innovative cement slurries that improve bonding, compressive strength and sealing capabilities for high-enthalpy geothermal wells in order to ensure casing strings protection and zonal isolation at elevated temperatures and pressures (up to 450 °C and >100 bars).

Cement samples from the IDDP-1 geothermal well in Iceland, which were exposed to temperatures up to 450 °C, have been analysed chemically and mechanically in the GeoWell project (Fig. 1). This gave a unique insight into the performance of Portland cement mixtures under high-temperature geothermal conditions. The results showed that a) Portland cement mixtures including silica are actually appropriate for the use in geothermal applications and b) the amount of water in the samples was found to have created serious bleeding problems and needs to be reduced in optimized cement slurries. Numerical modelling on cement failure development has complemented the experimental results. Additionally, the current temperature limit of chemical predictions of cement operation processes is being lifted up to 450 °C.

The issue of pressure build-up in the cement sheath has been studied and information gathered about the pressure that is generated at different temperatures. The gathered data show that under critical conditions not only water pockets can lead to critical pressure build-up, but that high pressures can also be generated by (surplus) water that is present in the cement in excess to the amount strictly needed for the curing of the cement. Theoretical considerations and the lab tests resulted in a promising approach to develop "pumpable" cement with reduced water content, without reducing its sealing properties.

Studies are being performed on a ductile intermediate layer between the cement

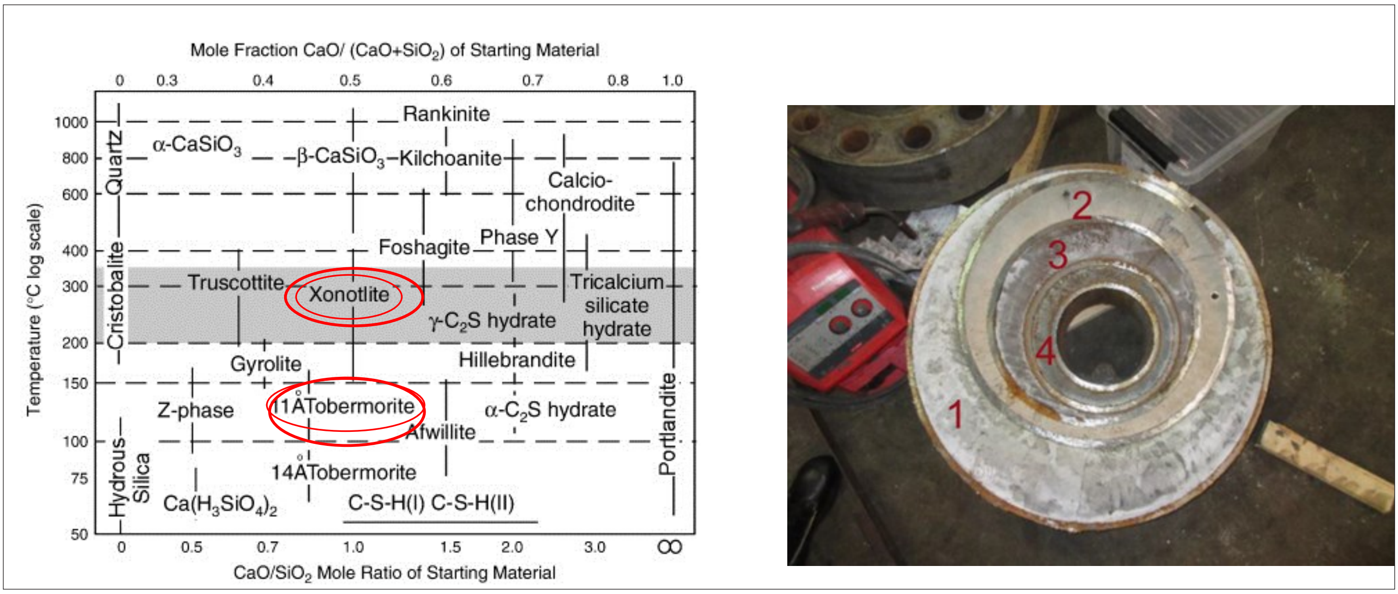

Fig. 1 Phases that occur in cement depending on Ca/Si ratio and temperature (left, from Meller et al. after Taylor [1, 2] ; red-rimmed minerals were found in IDDP-1 cement) and picture of top view of the retrieved casings at the top of the IDDP-1 well (right). (1–4: cement layers)

and the steel casing that could take up strains generated by temperature changes and increase the integrity of the system. Different nanomaterials have been evaluated for their potential to reduce friction in small-scale tests. In the first screening tests, silica and boron nitride performed better than carbon.

High-temperature Resistant Composite Casings

Among the innovative technologies of the GeoWell project is the development of high-temperature composite casings (HTCC – Glass fibre reinforced polymers) for geothermal applications. The main goal is to increase the application temperature from around 85°C to 140–170 °C, which is relevant for a wide range of geothermal applications. A list of requirements and specifications for HTCC was established and a concept design for a HTCC connection has been made.

The research showed that the solution could not be found in improving the adhesive connection, but that it would be more promising to focus on the development of a mechanical connection. Recent efforts have been dedicated to material selection for both the mechanical (threaded/friction fit) connection and the matrix material of the composite pipes.

Flexible Coupling of Casings

Plastic straining of casings due to large temperature differences regularly results in casing failures. The objective is to develop flexible couplings for casings that allow axial movement of casing segments due to thermal expansion of the casing, which results in stresses being below the yield strength of the casing material. No axial plastic strains are therefore generated, which is important for the well integrity during its lifetime. If the well needs to be shut-in or quenched with water for maintenance, no axial tension that can lead to casing failure is generated in the casing as is the case in conventional wells.

A casing coupling prototype was designed and a patent application has been filed (Fig. 2). Three full-scale prototypes have been built and structural properties as well as sliding mechanism tested successfully at ambient temperatures in the laboratory. The concept of flexible couplings has shown to be of high interest in the geothermal industry and most likely it will be tested in a geothermal well in the near future, but that is outside the scope of the GeoWell project.

Casing Materials

The goal is to reveal and test standard and innovative casing materials that withstand thermal loading and aggressive geothermal downhole environment to ensure casing integrity and extend the longevity of geothermal wells. Cladded casing materials will also be tested in-situ.

A technical report on the various corrosion problems found in geothermal wells as well as candidate materials for casings and casing couplings was prepared. Preparations are ongoing for tensile testing that will expand the existing curves, showing how the strength reduces with temperature for API materials, up to 550 °C and establish such curves for other candidate materials. Also, corrosion resistance of materials in a new autoclave is being prepared for operation in real high-temperature geothermal environment.

Well Monitoring

Work has been ongoing on methods to identify processes that affect the integrity of a geothermal well by developing and testing distributed fibre optic sensing technologies to simultaneously measure temperature, strain and acoustic noise within the cemented annulus of a geothermal well.

The combined application of fibre optic cable, casing hardware, data acquisition systems, signal filtering supported by the assessment of the well construction process and well logging information, helped to gain confidence that strain and temperature readings can give a reliable picture of the downhole conditions in applications reaching temperatures up to 300 °C thoughout the lifetime of a well.

Successful trial tests have been performed in different downhole conditions

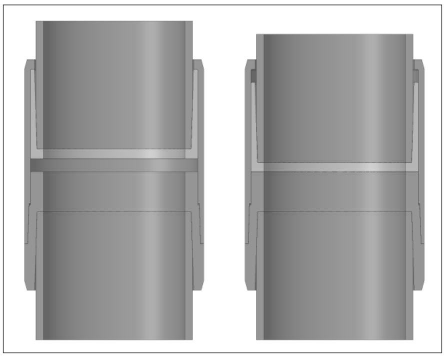

Fig. 2 Concept drawing revealing the main principles of the flexible coupling. On the left is the coupling shown in open mode, on the right in closed mode. (Patent application no. 050129 – Thorbjornsson 2015)

Fig. 3 Installation of fiber optic cable behind 9 5/8˝ casing in IDDP-2 well (Foto: Martin Lipus, GFZ)

from low to high temperature ranges at different depths in Germany and Iceland, including the IDDP-2 scientific drilling project (Fig. 3).

Risk Assessment

The work on risk assessment has targeted well integrity in the production phase. The goal is to raise the standard of risk analysis tools for geothermal wells to a standard that is comparable to that of oil & gas wells and propose a risk management framework that can be used for deep geothermal wells. A thorough literature study as well as a survey have been performed to map the status and availability of qualitative and quantitative risk assessment methods. Information was received from stakeholders from both the oil & gas and the geothermal industries. The results have been presented in project reports and in an open webinar, showing e. g. that well barriers are generally less focused in the geothermal industry.

A list of barriers and associated failure modes in the geothermal production phase has been compiled using available guidelines, standards and industry input. Further, methods to quantify the risk of the selected failure modes, including models for failure mechanisms, have been identified. The failure modes covered are representative of commonly occurring problems in geothermal wells, also those operating in high temperature conditions.

Upcoming work within the GeoWell project on this topic will include the evaluation of European regulations and standards on geothermal well integrity and risk assessment requirements and a proposal for improvements, culminating in a proposed risk management framework for geothermal wells. The framework will be demonstrated on the new cement and casing technologies developed in the project.

Conclusions

The work during the first two years of the GeoWell project has already shown interesting results. Several reports have been prepared and those that are public are available on the project website, together with general information about the project (*http://geowell-h2020.eu*). The work so far has resulted in tangible products, indicating that implementing the GeoWell project will have a positive impact on the targeted geothermal technologies related to construction and operation of geothermal wells. ■

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Lterature

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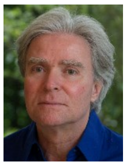

Willem de Jong holds a degree in Industrial design from Delft University of Technology, the Netherlands. He is the co-founder and co-owner of Acquit Business Development BV (2001) and Akiet BV (2015).

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