New methods in geophysical exploration and monitoring with DTS and DAS

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Summary:

The development of new subsurface technologies often calls for measurements under extreme conditions and/or extended sensing requirements. Within recent years, continued developments in fiber-optic sensing have led to new possibilities for geophysical exploration and monitoring. These include several distributed methods, where data is recorded with high spatial and temporal resolution over long distances using the optical fiber as a sensor, exploiting different scattering mechanisms. Here we outline some new technologies in this context within case studies from different research projects including permanent installation of fiber-optic sensor cables behind casing, monitoring of high-temperature wells, a hybrid wireline logging system, and seismic recording using long-distance surface cables. We show that fiber-optic sensing opens up new possibilities for geophysical measurements with a broad range of applications in well logging and seismic exploration and monitoring. More time and cost effective deployment is possible, but continued research and development efforts are necessary to address remaining challenges.

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Introduction

The development of new subsurface technologies, e.g. for reducing greenhouse gas emissions, monitoring of natural hazards, or development of unconventional resources, often call for measurements under extreme conditions and/or extended sensing requirements. Within recent years, continued developments in fiber-optic sensing have led to new possibilities for geophysical exploration and monitoring.

Fiber-optic sensing includes distributed methods where data is recorded with high spatial and temporal resolution along an optical fiber of up to several 10s of km length, mostly using the principle of optical time-domain reflectometry (OTDR). Distributed temperature sensing (DTS) is usually based on Raman optical scattering, while distributed acoustic or vibration sensing (DAS/DVS) is exploiting Rayleigh, and some other distributed strain sensing (DSS) methods Brillouin scattering. In addition to this, a number of different point sensor types, like fiber Bragg gratings and Fabry-Perot interferometers, can be used for measurement of e.g. strain, pressure, and temperature, as well as refractive index or individual chemical components. Depending on the individual deployment conditions and sensing method, an appropriate fiber type, sensor cable design, and deployment method have to be chosen.

At the GFZ German Research Centre for Geosciences, the first borehole tests using fiber-optic methods for geophysical applications have been performed by Hurtig et al. (1993) and since then downhole sensor cables have been deployed in more than 20 wells at depths up to 4.300 m and at temperatures ranging between -40 and over 300 °C within different research projects. In the following, some new key methods for geophysical exploration and monitoring using fiber-optic sensing developed and applied therein will be outlined.

Permanent installation of fiber-optic sensor cables behind casing

Heat-pulse method for measurement of in-situ thermal conductivities

At the Ketzin site, several wells have been equipped with permanent fiber-optic sensor cables behind casing (Prevedel et al. 2008), primarily for monitoring of temperature effects related to injection of CO_2 with DTS (Henninges et al. 2011b). Using electrical conductors as a controlled heat source and monitoring temperature changes with DTS, thermal conductivities along the boreholes have been determined using the heat-pulse method (Freifeld et al. 2009). By evaluating early- and late-time data, we investigated properties of both the completion of the well and the surrounding rock formation, see Fig. 1 and Prevedel et al. (2014).

Vertical seismic profiling (VSP) using DAS

An initial test DAS-VSP survey using the permanent sensor cables installed at Ketzin had revealed that superior data quality can be achieved with sensor cables cemented in place compared to other installation methods (Daley et al. 2013). Based on this, a follow-up survey was performed, where a vibro-truck was deployed as the seismic source at 23 shot points while DAS data was acquired in four wells simultaneously (Götz et al. 2015). With a higher source effort, the data shows a similar signal-to-noise level compared to data acquired using conventional geophones. The overall operational effort is nevertheless much lower, allowing for very cost effective, high-resolution 3D seismic imaging close to the boreholes.

Long-term monitoring of abandoned wells

Another important aspect is that wells equipped with permanent sensor cables can be used for downhole monitoring even after abandonment. For this, an appropriate abandonment procedure must be applied, where the cables remain intact and the surface ends accessible, as performed at the Mallik site (NWT, Canada). In three wells repeated DTS measurements were performed to a depth of 1200 m over several years after abandonment enabling to monitor the decay of the thermal disturbance after drilling and measurement of undisturbed formation temperatures (Henninges et al. 2005).

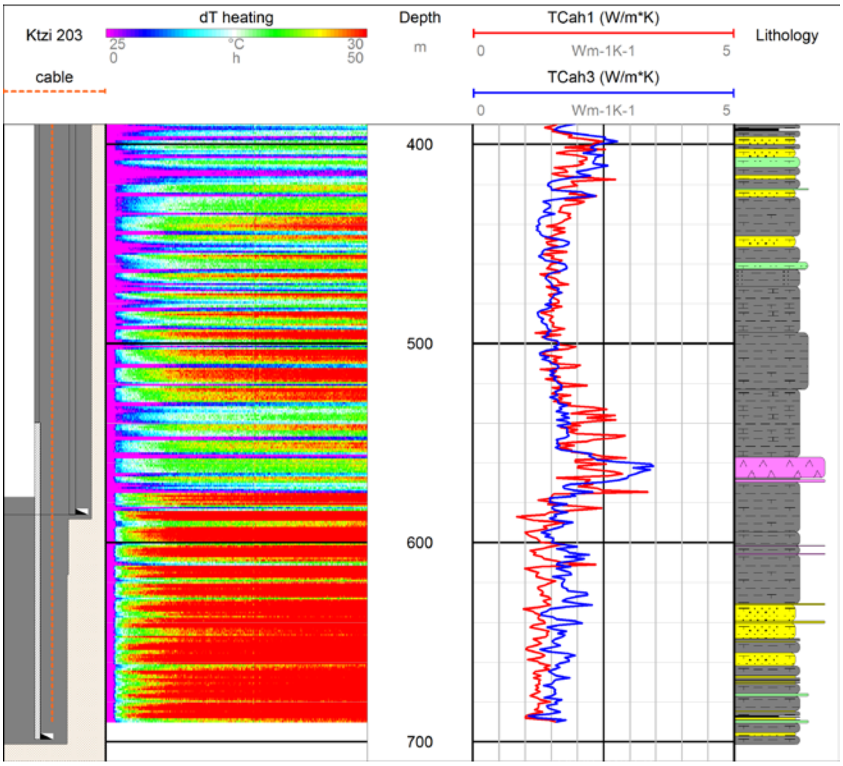

Figure 1: *Results of heat-pulse measurements in well Ktzi 203. Left: Temperature changes. Right: Calculated thermal conductivities (TC) for early- (red) and late-time data (blue), representative for the near and far field around the well, respectively.*

Monitoring of high-temperature wells

A well-known advantage of fiber-optic sensors is that they can tolerate higher temperatures compared to conventional electronic sensors. Nevertheless, fibers with appropriate coating materials have to be chosen for deployment at elevated temperatures. In the HE-35 high-temperature geothermal well (Iceland), a cable with a "hermetic" carbon/polyimide-coating fiber was installed, also to avoid the effect of hydrogen darkening. It was successfully used for DTS-monitoring during a flow test at temperatures up to 230 °C over a period of 14 days, but also showed different signs of degradation, especially after exposure to temperatures above 300 °C (Reinsch et al. 2013). We see creation of inert atmosphere around the fiber and improvement of attenuation characteristics of fibers with high-temperature tolerant coating materials, e.g. metal-coated fibers, as important elements to overcome current limitations.

Hybrid wireline cable deployment

In already existing wells or cases when the completion type makes permanent installation to the target depth difficult, a cable can also be lowered down inside the casing or tubing. When using distributed methods, one of the main advantages over classical wireline logging operations is that also very long profiles can be monitored simultaneously without tool or cable movement. As the repertoire of fiber-optic sensors is currently still limited, a hybrid wireline logging system additionally allowing for deployment of classical electric tools like gamma-ray or casing-collar-locator for depth correlation has been developed (Henninges et al. 2011a). This system was used for flow profiling during a production test in a 4.300 m deep well at the Groß Schönebeck site (Henninges et al. 2012), revealing important information on the reservoir behaviour of this enhanced geothermal system (Blöcher et al. 2016).

Long-distance surface cables for seismic recording

Apart from boreholes, fiber-optic sensing also opens up new possibilities for geophysical measurements at surface, especially since extensive networks of fiber-optic cables for telecommunication and data transmission already exist almost worldwide. In order to test the applicability for seismological studies, DAS data was acquired over a period of 9 days along a 15 km telecom cable in the Reykjanes geothermal field in Iceland (Reinsch et al. 2016). Preliminary results show that the collected data enables to monitor earthquake activity and explore subsurface properties at crustal scale (Jousset et al. 2016).

Conclusions

Fiber-optic sensing opens up new possibilities for geophysical measurements with a broad range of applications in well logging (e.g. temperature and production logging, well integrity monitoring) and seismic exploration and monitoring. Some of the main advantages are that fiber-optic sensors are usually more ruggedized, have a higher temperature tolerance, and are easier to deploy compared to conventional electronic sensors. Distributed methods enable sampling with high spatial and temporal resolution over long distances. As a result, more time and cost effective deployment is possible. Continued research and development efforts are nevertheless necessary to address existing challenges, e.g. lower signal-to-noise ratio, very large data volumes, directional sensitivity, or the currently still limited set of measurement parameters.

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References

Blöcher G, Reinsch T, Henninges J, Milsch H, Regenspurg S, Kummerow J, Francke H, Kranz S, Saadat A, Zimmermann G, Huenges E (2016) Hydraulic history and current state of the deep geothermal reservoir Groß Schönebeck. Geothermics 63:27-43. doi:10.1016/j.geothermics.2015.07.008

Daley TM, Freifeld BM, Ajo-Franklin J, Dou S, Pevzner R, Shulakova V, Kashikar S, Miller DE, Goetz J, Henninges J, Lueth S (2013) Field testing of fiber-optic distributed acoustic sensing (DAS) for subsurface seismic monitoring. The Leading Edge 32:699-706. doi:10.1190/tle32060699.1

Freifeld BM, Daley T, Hovorka S, Henninges J, Underschultz J, Sharma S (2009) Recent advances in well-based monitoring of CO_2 sequestration. Energy Procedia 1 (1):2277-2284. doi:10.1016/j.egypro.2009.01.296

Götz J, Lüth S, Henninges J, Reinsch T (2015) Using a fibre optic cable as Distributed Acoustic Sensor for Vertical Seismic Profiling at the Ketzin CO_2 storage site. Conference Proceedings, 77rd EAGE Conference & Exhibition, Madrid, Spain (CD-ROM). doi:10.3997/2214-4609.201413363

Henninges J, Baumann G, Brandt W, Cunow C, Poser M, Schrötter J, Huenges E (2011a) A novel hybrid wireline logging system for downhole monitoring of fluid injection and production in deep reservoirs. Conference Proceedings, 73rd EAGE Conference & Exhibition, Vienna, Austria (CD-ROM):C043

Henninges J, Brandt W, Erbas K, Moeck I, Saadat A, Reinsch T, Zimmermann G (2012) Downhole monitoring during hydraulic experiments at the In-situ Geothermal Lab Groß Schönebeck. Proceedings, 37th Workshop on Geothermal Reservoir Engineering, Stanford, USA (CD-ROM):51-56

Henninges J, Huenges E, Burkhardt H (2005) In situ thermal conductivity of gas-hydrate-bearing sediments of the Mallik 5L-38 well. J Geophys Res 110:B11206. doi:10.1029/2005JB003734

Henninges J, Liebscher A, Bannach A, Brandt W, Hurter S, Köhler S, Möller F, CO_2SINK Group (2011b) P-T-rho and two-phase fluid conditions with inverted density profile in observation wells at the CO_2 storage site at Ketzin (Germany). Energy Procedia 4:6085–6090. doi:10.1016/j.egypro.2011.02.614

Hurtig E, Schrötter J, Grosswig S, Kühn K, Harjes B, Wieferig W, Orrell RP (1993) Borehole temperature measurements using distributed fibre optic sensing. Sci Drill 3 (6):283-286

Jousset P, Reinsch T, Henninges J, Blanck H, Ryberg T (2016) Strain and ground-motion monitoring at magmatic areas: ultra-long and ultra-dense networks using fibre optic sensing systems. EGU Geophysical Research Abstracts 18:EGU General Assembly 2016 (Vienna, Austria), EGU2016-15707

Prevedel B, Martens S, Norden B, Henninges J, Freifeld BM (2014) Drilling and Abandonment Preparation of CO_2 storage wells – Experience from the Ketzin pilot site. Energy Procedia 63:6067-6078. doi:10.1016/j.egypro.2014.11.639

Prevedel B, Wohlgemuth L, Henninges J, Krüger K, Norden B, Förster A, the CO_2SINK Drilling Group (2008) The CO_2SINK boreholes for geological storage testing. Sci Drill 6:32-37. doi:10.2204/iodp.sd.6.04.2008

Reinsch T, Henninges J, Ásmundsson R (2013) Thermal, mechanical and chemical influences on the performance of optical fibres for distributed temperature sensing in a hot geothermal well. Environ Earth Sci 70:3465–3480. doi:10.1007/s12665-013-2248-8

Reinsch T, Jousset P, Henninges J, Blanck H (2016) Distributed Acoustic Sensing Technology in a Magmatic Geothermal Field – First Results From a Survey in Iceland. EGU Geophysical Research Abstracts 18:EGU General Assembly 2016 (Vienna, Austria), EGU2016-16670