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The CO_2SINK boreholes for geological CO_2-storage testing

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Abstract

This paper reports the well design, drilling and completion operation as well as the coring technique applied in the CO_2SINK project. Three boreholes, one injection well and two observation wells have been drilled to a total depth of about 800 m. 200 m of recovered 6" core material has been real-time analysed in a research field lab. The wells have been completed as "smart" wells, containing a variety of permanently installed down-hole sensors for the continuous monitoring of the CO_2 in the reservoir. All wells were cased with stainless final casings equipped with pre-perforated sand filters in the reservoir zone and wired on the outside with fiber-optical and multi-conductor copper cables. The reservoir casing section is externally coated with a fiber-glass-resin wrap for electrical insulation.

Keywords: drilling, coring, completion, mud loss, filter screens, geophysical monitoring, DTS, ER

1. Introduction

The European scientific carbon dioxide storage project CO_2SINK (CO_2 Storage by Injection into a Natural saline aquifer at Ketzin) is performed in a saline aquifer in NE- Germany. The major objectives of CO_2SINK are the advancement of the science and practical processes and eventually the provision of operational field results to assist in the development of standards and regulations for a future geological storage of CO_2. Three boreholes, one injection and two observation wells have been drilled in 2007, each to a depth of about 800 m. The wells, 50 m to 100 m from each other, are all completed as "smart" wells containing a variety of permanent down-hole sensing equipment, which has proven its functionality during its baseline surveys before injection start (Fig. 1).

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The plan is to inject into the aquifer over a period of two years a volume of up to 60,000 tons of CO_2. Injection has started in spring 2008 and is intended to last for two years to allow for monitoring of migration and fate of the injected gas by means of a combination of down-hole monitoring with surface geophysical surveys [1]. This report summarizes design, well construction and completion operations of the three CO_2SINK boreholes.

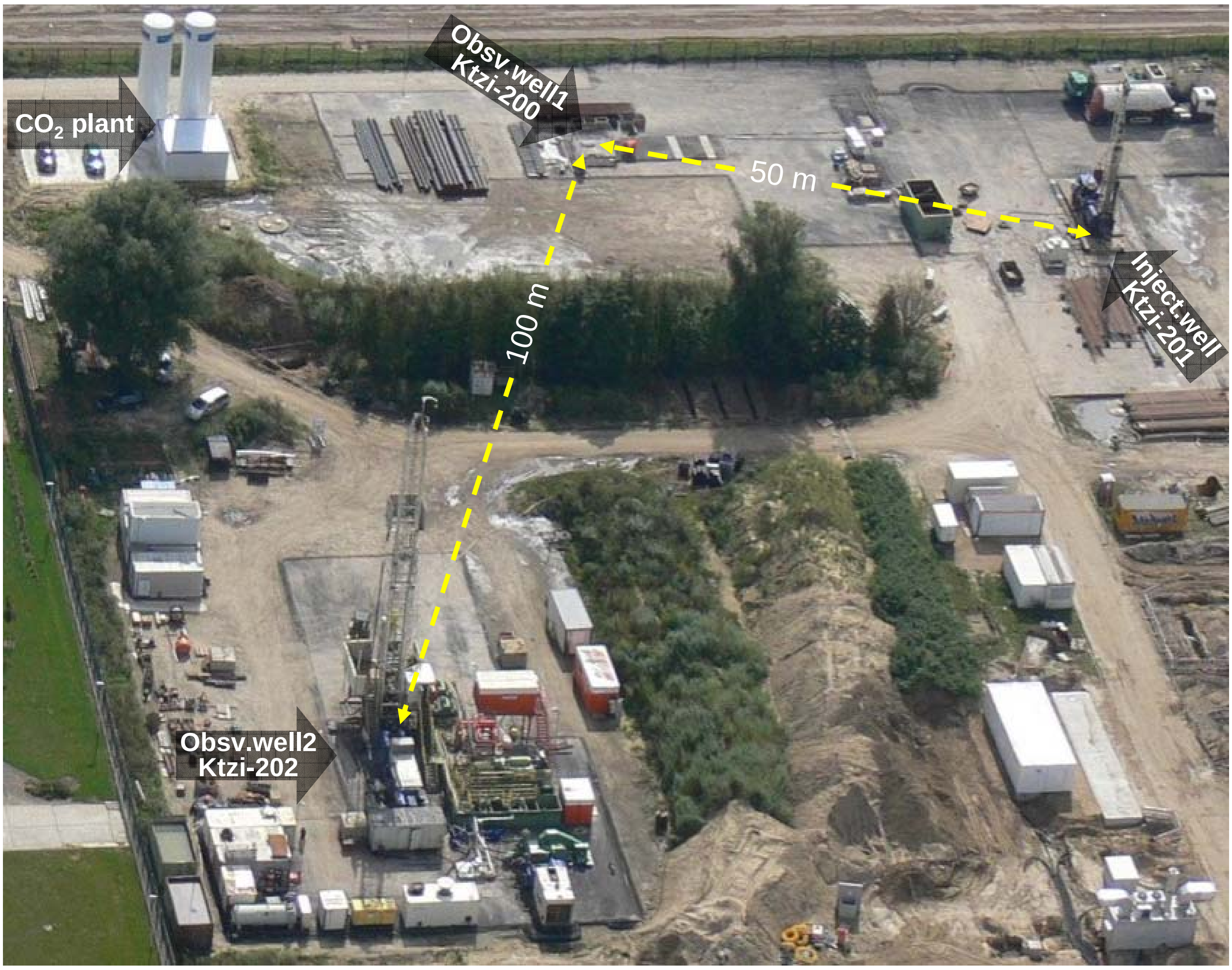

Fig. 1: CO_2SINK drilling site (aerial view), with work-over rig on injection well (CO_2 Ktzi 201/2007, top-right) and drill rig on observation well #2 (CO_2 Ktzi 202/2007, bottom-left). Observation well #1 (CO_2 Ktzi 200/2007) and CO_2 storage tanks with pump house (top-left) are already finished.

2. Geological background

The CO_2SINK site is located near the town of Ketzin, 40 km to the west of Berlin, Germany. Geologically, the site is located in the Northeast German Basin, a sub-basin of the Central European Basin System. The sedimentary succession is several kilometers thick containing geological formations of Permian to Quaternary age and contains several deep saline aquifers. The CO_2 is injected into the Stuttgart Formation (Fig. 2) of Triassic age at the southern flank of the gently dipping Ketzin anticline.

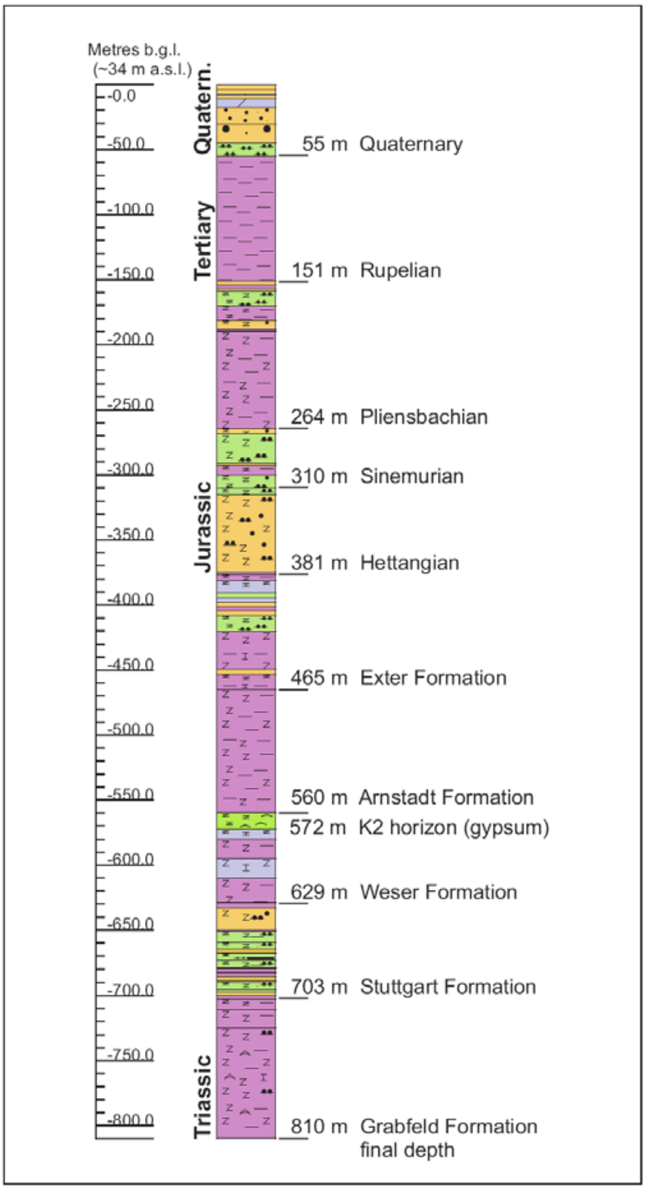

Fig. 2: Condensed geological profile of the CO_2 Ktzi 200/2007 well. Lithological color code: mudstone (magenta), siltstone (green), sandstone (yellow), anhydrite (light blue).

The Stuttgart Formation at Ketzin rests at depth of about 630 – 710 m, at temperatures of about 38°C. The formation is made up of channel-(string)-facies (sandstones, siltstones) of good reservoir properties that alternate with flood-plain-facies rocks (mostly mudstones) of poor reservoir quality [2]. The Stuttgart Formation is underlain by the Grabfeld Formation, which is a thin-bedded succession made up of marlstone, marly dolomite and thin anhydrite or gypsum beds deposited in a clay/mud-sulfate playa environment [3]. The top seal of the Stuttgart Formation is the Weser Formation, which also is of continental playa type, consisting mainly of clayey and sandy siltstones that alternate with carbonates and evaporites [3]. The high clay-mineral content and the observed pore-space geometry of these rocks confirm sealing properties appropriate for CO_2 capture [4]. The Weser Formation is overlain by the Arnstadt Formation of mud/clay-carbonate playa type [3] exhibiting similar sealing properties. The two cap-rock formations immediately overlying the Stuttgart Formation are about 210 m thick.

3. Borehole design and drilling / completion operation

All three CO_2SINK wells were planned to be vertical with the same casing layout, including a stainless casing, equipped with pre-perforated sand filter segments in the reservoir section and fiber-optical and multi-conductor monitoring sensors and cables cemented on the outside (Table 1). The choice of the relative well positions has been guided by geological and physical constraints to optimize the spatial resolution of the various monitoring methods, e.g. cross-hole seismic and Electrical Resistivity Tomography (ERT), in accordance to the planned injection volume of CO_2.

Table 1: Casing design for the CO_2SINK wells

	Depth	Diameter		Weight	Quality	Connection
	[m]	[inch]	[mm]	[lb/ft]		
Stand pipe	30	24.0	610	125.5	4140	welded
Conductor String	150	18.625	473	87.5	X56	Buttress-BTC
Reserve String	340	13.375	340	54.5	K-55	Buttress-BTC
Intermediate String	590	9.625	244	36	K-55	Buttress-BTC
Production String	800	5.5	140	20	13Cr80 (outside coating)	VAM Top
Injection String	561	3.5	89	9.3	C-95 (inside coating)	TS-8

Drill site construction started in December 2006, and the drilling operation commenced on March 13, 2007 with the mobilization of a truck-mounted 600 kN hook load capacity and top-drive equipped rotary drill rig. All the Ketzin wells were drilled with an inhibited KCl water-based mud system, with the exception of the top-hole section in the fresh-water aquifers, where a K_2CO_3-water-based system was preferred for environmental reasons. Both mud systems were conditioned at 1.05 to 1.16 g/cm^3 density and starting hole size was 23” on all wells with the exception of well nbr.1, where a “shallow gas” procedure was implemented for safety reasons, in order to avoid spills in the situation the wells would encounter high pressurized shallow gas from a past natural gas storage activity in the Jurassic section. For this purpose, the top-hole section of the first borehole was pre-drilled in 8 ½” with a blow-out preventer/diverter/gas-flare installation on the rig to capture and control unexpected and sudden shallow gas influxes. As no stranded shallow gas was encountered during drilling, as also confirmed by reconnaissance wire-line logging and surface seismic processing, this pilot drilling was consequently omitted on the second and third well. 18 5/8” casing running and cementation with stinger to surface was performed in all three wells without problems.

In the following 12 ¼” sections, the wells penetrated the abandoned Jurassic aquifer systems, where in the past natural gas storage was performed and for which under-balanced pressure regimes were supposed. As expected, all wells encountered a minimum of three loss circulation zones between 366 m and 591 m with cumulative mud losses of 550 m^3 for the entire project. The addition of medium- to coarse-grained shell grit to the drill mud cured the loss of circulation and brought the wells safe to the 9 5/8” casing depth between 588 m to 600 m. For the event of unmanageable mud losses, hole opening to 17 ½” and cementation of a reserve 13 3/8” casing was provided as an option for all three wells.

The lower part of Weser Formation and the Stuttgart Formation was cored in all wells with a specially designed $CaCO_3$ water/polymer drill-in mud (1.1 g/cm^3). A total of 200 m core section for detailed investigations of the CO_2 injection reservoir and its sealing property were recovered > 95% with a 6” x 4” wire-line coring system using poly-crystalline diamond compact core bits. The 6 ¼” core hole sections were consequently enlarged to 8 ½” and all wells finally deepened to approximately 800 m in order to accommodate sufficient sensor spacing for the to be installed behind-casing monitoring arrays.

Stainless steel 5 ½” production casings (Fig. 3) were installed and cemented in all three boreholes with 3 – 4 lines of monitoring cables on the outside. The cables were terminated at the wellhead and fed from the inside – out at the drilling spool below the casing slips. The 150 m long bottom section of the 5 ½” casing at the reservoir is externally coated with a fiber-glass-resin wrap for electrical insulation and support for the ERT measurement. The cement selected in all casing cementations was standard class-G mixed with fresh water and no chemical additives (SG = 1.98 kg/l), with the exception of the stage cementation above the reservoir sand-face, for which a specially designed CO_2-resistant class-G salt cement was selected. A staged cementation program was planned around the application of a newly developed swellable elastomer packer and stage cementation down-hole tools. This rather complex cementing procedure was given preference over perforation work that would have caused unmanageable risks of potential damage of the outside casing cables.

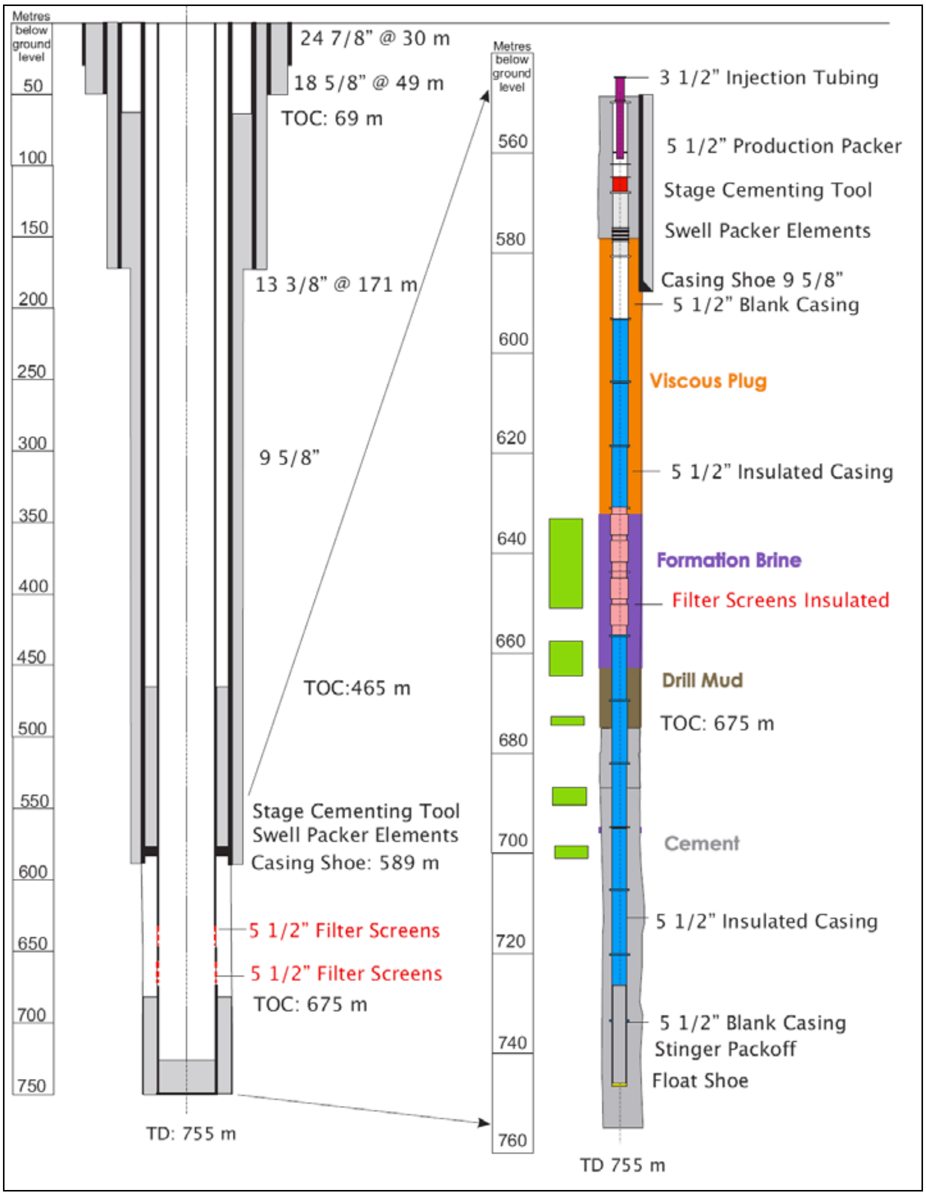

Fig. 3: Drilling design and well-completion details of the CO_2 Ktzi 201/2007 well

The CO_2 injection well was completed with internally coated premium 3 ½" production tubing, including a permanent production packer above the injection horizon, a fiber-optic pressure/temperature gauge above the packer and a wire-line retrievable subsurface safety valve at 50 m depth below the well head. The optical cables and hydraulic safety valve actuation lines were clamped to the outside of the production tubing and fed pressure tight to the outside at the tubing hanger adaptor below the X-mas tree in a similar way as the permanent monitoring cables outside the 5 ½" production casing.

4. Installation of permanent down-hole sensors for CO_2 monitoring

Geophysical monitoring plays a crucial part in CO_2SINK to delineate the migration and saturation of the injected CO_2. The equipment permanently installed in the injection well and in the two observation wells are made of state-of-the art as well as newly developed prototype sensors. The data from these monitoring systems will be interpreted in combination with data from periodic seismic acquisitions (VSP, MSP, and cross-hole) and periodic fluid sampling as well as cased hole wire-line logging (Reservoir Saturation Tool). For scientific monitoring following components were permanently installed in the CO_2SINK wells:

- fiber-optic sensor cable loop for Distributed Temperature Sensing (DTS; all wells).
- a two-line electrical heater cable (2 wells)
- a vertical electrical resistivity array consisting of fifteen toroidal steel electrodes, 15-line surface connection cable (all wells) for ERT measurements.
- fiber-optic pressure/temperature (P/T) sensors, fiber-optic surface connection cable (at injection string only).

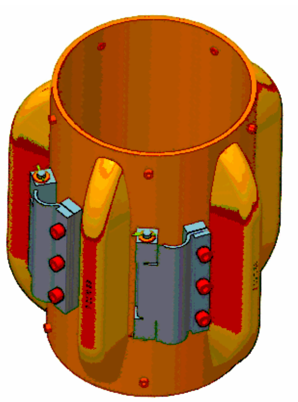

Fig. 4: Special casing centralizer / cable protector

The technical layout of the Vertical Electrical Resistivity Array (VERA) was designed according to numerical forward modelling and assuming electrical properties of pre- and post-injection scenarios. The finally determined number of electrodes, their spacing along each well, and the horizontal-to-vertical ratio of the image plane for each well and for the whole triangular setup results in a suitable compromise between best resolution of CO_2 migration features and installation cost of the array.

Custom-made casing centralizers were specially fabricated for outside-casing installation of sensor cables, for centralizing the casing inside the borehole, and for protection of cables from mechanical damage during installation (Fig. 4). Within the 150 m zone, where the ERT electrodes are placed, the steel casing was electrically isolated outside using a double layer fiber-glass coating, cured for electrical insulation in a resin compound.

The monitoring cables were delivered to the rig site in single drums and mounted on hand-operated spooling racks. Depending on their size, they were either hoisted onto the drill floor or positioned on the ground sideways to the substructure of the rig. For installation in the borehole, the cables were taken from the drums, fed through sheaves positioned half way in the derrick and then guided together with the installed casing into the hole. A special modified casing spider with spaced out slip elements had to be used in order to protect the cable from being damaged while casing running operation. The installation of such a permanent monitoring array with all associated sensors, cable protectors and casing centralizer on the 5 ½" casing to 800 m depth took approximately 24 hours. This represents a acceptable 50% overtime compared to conventional casing running without outside cables.

The installation of the monitoring arrays was finished by threading the cables through the casing spool at the wellhead, which was subsequently pressure-sealed utilizing a cable-stuffing box. All sensors and cables survived the drilling and installation work without damage and are fully functional in all three wells for the injection phase.

The DTS monitoring cables provided also valuable online monitoring and control of the cementing and well treatment operations and information about the positions of the cemented sections during the setting of the cement. This information was verified by subsequent industry-standard cement-bond logs.

5. Field laboratory

During the drilling operations, the set-up CO_2SINK field laboratory was fully operational. The laboratory contained core-cleaning and core-sealing facilities, a full-core imager and a GeoTek gamma-ray density core logger. The field lab was designed to record and describe a high core-run volume within a short handling time to quickly generate the litho-log for the drilled borehole sections and to identify the intervals of good reservoir quality. This procedure was necessary in order to be able to quickly proceed with decision making on the selection of the borehole intervals to be completed with filter casings through which the CO_2 would be injected into the formation and monitored.

Prior to geological description, core from mudstone intervals required cleaning with synthetic formation water, reorientation, and scanning unrolled using an optical core scanner. Later on in the project the “hot-shot” core analysis of the reservoir sections was included. From the geological core and cutting descriptions and interpreted petrophysical well logs, stratigraphic-lithologic logs (Fig.1) were finally generated for all three CO_2SINK wells in order to refine the geological model. Later on performed petrographical and mineralogical studies as well as geochemical analyses on the cores from the reservoir and cap-rock helped to understand the conditions at micro scale, for example as a basis for future fluid-rock-alteration modeling.

6. Outlook

The entire drilling and completion campaign ended on August 14, 2007 after 155 drilling days with no major incident or severe accident. After the completion of the CO_2 injection program in the year 2009/2010, the wells will be fully abandoned, the site reconditioned and the land given back to the land owner.

Acknowledgments

We would like to thank all partners of the CO_2SINK project for their continued support and contributions that helped to finish the three wells in a healthy and environmentally safe manner. Special thanks go to Shell International and StatoilHydro for their most valuable advice and operational support during the planning and drilling phase in Ketzin and to VNG AG for letting us use their site at Ketzin. The CO2SINK project receives its funding from the European Commission (Sixth Framework Program, FP6) and two German ministries, the Federal Ministry of Economics and Technology (CO2-Reduction-Technologies for fossil fuelled power plants, COORETEC Program – CORTIS and CORDRILL Project), and the Federal Ministry of Education and Research (CO_2 Storage, Monitoring and Safety Technology / COSMOS Project, GEOTECHNOLOGIEN Program).

Most importantly this project would not have been possible without the never ending efforts and enthusiasm of Professor Dr. Borm, the founding father and first director of the CO_2SINK project.

Photo credits:

Fig. 1. VNG - Verbundnetz Gas AG, Leipzig, Germany

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