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Progress Report on the First European on-shore CO_2 Storage Site at Ketzin (Germany) – Second Year of Injection

S. Martens[a]*, A. Liebscher[a], F. Möller[a], H. Würdemann[a], F. Schilling[a,b], M. Kühn[a], and Ketzin Group

[a]*GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany*
[b]*KIT Karlsruhe Institute of Technology, University of Karlsruhe, Engler-Bunte-Ring 14, 76131 Karlsruhe, Germany*

Abstract

The pilot study at the Ketzin site close to Berlin (Germany) aims at in-situ testing of geological storage of CO_2 in a saline aquifer. Following site characterization and the drilling of one injection well and two observation wells, the in-situ field laboratory has been fully in use since CO_2 injection started in June 2008. After two years of operation, about 36,000 tons of CO_2 have been injected. This paper presents the key results from the second year of injection and the interdisciplinary monitoring concept in the frame of the European project CO_2SINK (**CO_2 S**torage by **I**njection into a **N**atural Saline Aquifer at **K**etzin) and accompanying projects.

CO_2 storage; Ketzin test site; injection; reservoir monitoring; numerical modeling

1. Introduction

At Ketzin, north-eastern Germany, the German Research Centre for Geosciences operates Europe's first on-shore CO_2 storage site with the aim of increasing the understanding of geological CO_2 storage in saline aquifers. The project, funded by the EU project CO_2SINK, began in April 2004. The drilling of one injection well (CO_2 Ktzi 201/2007; abbrev. Ktzi 201) and two observation wells (CO_2 Ktzi 200/2007, CO_2 Ktzi 202/2007; abbrev. Ktzi 200 and Ktzi 202) (Fig. 1), each to a depth of about 800 m, was completed in 2007 [1]. The wells are equipped with a variety of sensors and cables permanently installed on the casing. This smart casing concept has proven its feasibility in baseline surveys before injection and from repeat measurements after the start of injection.

The CO_2 injection commenced on June 30, 2008 [2]. Site operation is regulated under the mining legislation of the State of Brandenburg. The target reservoir is a sandstone aquifer of the Triassic Stuttgart Formation at a depth of about 630 to 700 m. An interdisciplinary monitoring concept integrating geochemical, geophysical and microbial investigations allows characterization of the reservoir and monitoring of the CO_2 subsurface behavior. Although the CO_2SINK project ended in March 2010, injection and research continues at Ketzin in order to complement the activities at the CO_2 storage site for a second period.

* Corresponding author. Tel.: +49-331-288-1965; fax: +49-331-288-1529.
E-mail address: martens@gfz-potsdam.de

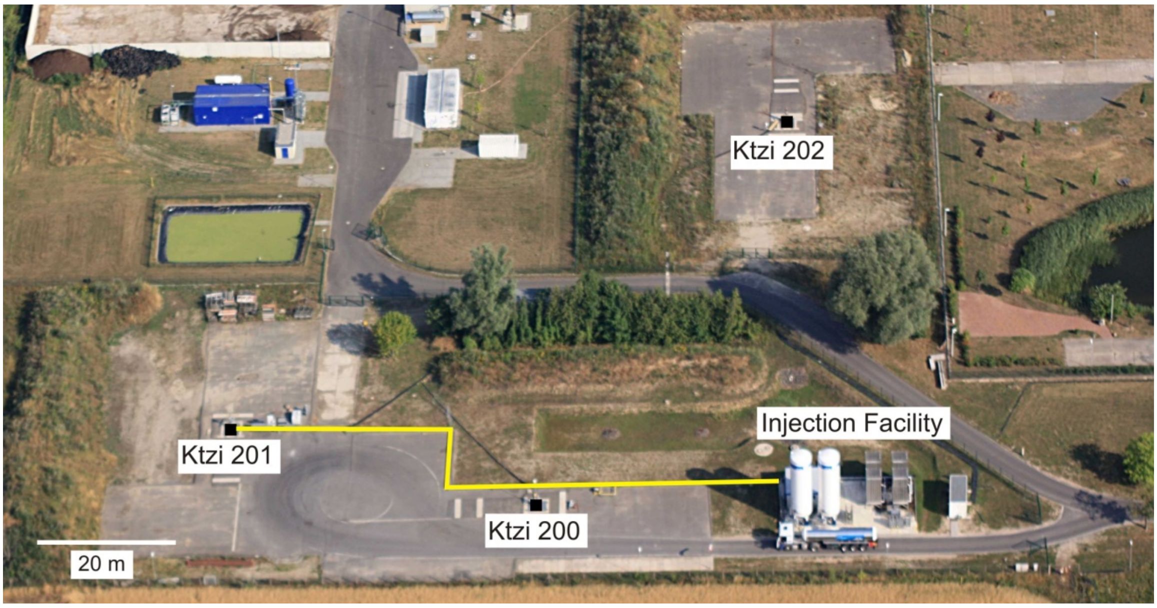

Figure 1 Overview of the Ketzin test site, July 2010.

2. Injection Operation

Since June 2008, the injection facility has been safely and reliably operated. Up to the end of June 2010, a total amount of about 36,000 tons of food grade CO_2 has been injected (Fig. 2). The overall injection rate since the start of operations is ~ 48 tons/day. Different injection rates have been applied to adjust the injection regime and to study the reservoir response. Some shut-ins for monitoring and sampling purposes have also taken place. During the first part of the second year of injection, the facility was mainly run with the maximum design rate of 3,250 kg/h. Since March 2010, injection has been operating at approximately 1,500 kg/h (~ 1,000 tons per month).

The downhole pressure is continuously monitored by a pressure/temperature (P/T) gauge installed in injection well Ktzi 201at a depth of 550 m. After the start of injection, pressure increased from initial conditions of 60.4 bar to a maximum pressure of 75.9 bar in June 2009 (Fig. 2).

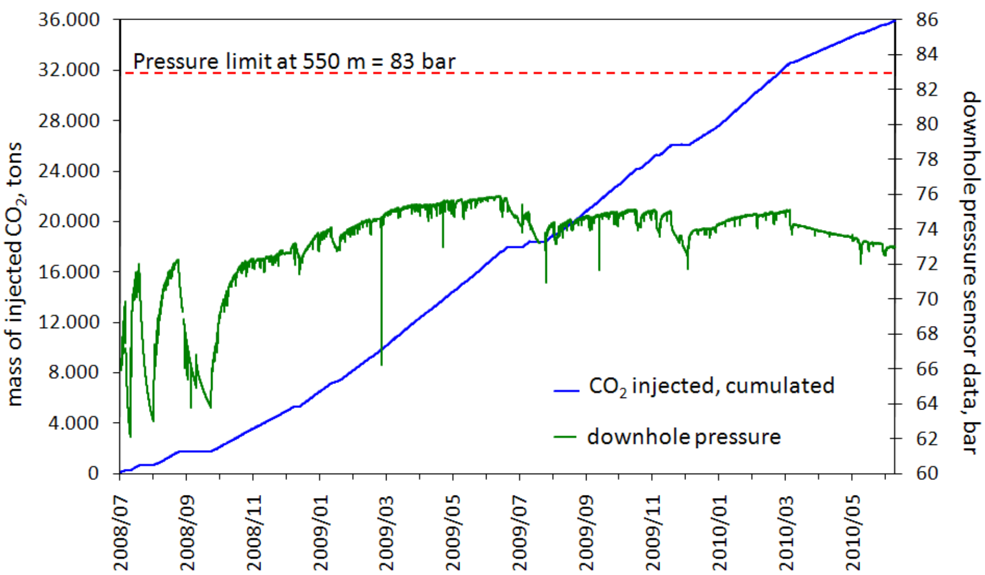

Figure 2 Downhole pressure (green) at 550 m vs. cumulated mass of CO_2 injected (blue).

Since about August 2009, pressure has stabilized at ~ 74 bar. A conservative pressure limit has been set by the Mining Authority to not exceed 85 bar at the injection point, which translates to ~ 83 bar pressure at the P/T gauge (red broken line in Fig. 2). The data show that within 24 months of injection, reservoir pressure has never been near its pressure limit. During shut-in phase, monitoring indicated a prompt relaxation of the reservoir pressure within the expected range. Overall, the data shows normal reservoir behavior. Stabilization of reservoir pressure with time is due to the increased amount of CO_2, which pushed the gas-water contact further outward.

3. Monitoring Results

An interdisciplinary monitoring program comprising geophysical, geochemical, and microbial investigations is being performed at the Ketzin site [3]. Following baseline measurements prior to the injection [4], repeat measurements have been carried out or are in progress for joint interpretation and comprehensive characterization of the reservoir and the CO_2 migration process [5]. Routine sampling for chemical and microbial monitoring, logging as well as geophysical investigations is complemented by permanent monitoring (Fig. 3). Permanently installed components in the Ketzin wells include:

- a Vertical Electrical Resistivity Array (VERA) with 15 electrodes in each well
- a fibre-optic-sensor cable loop for Distributed Temperature Sensing (DTS) in each well
- a two-line electrical heater cable (Ktzi 201, Ktzi 202)
- a fiber-optic pressure/temperature sensor (Ktzi 201).

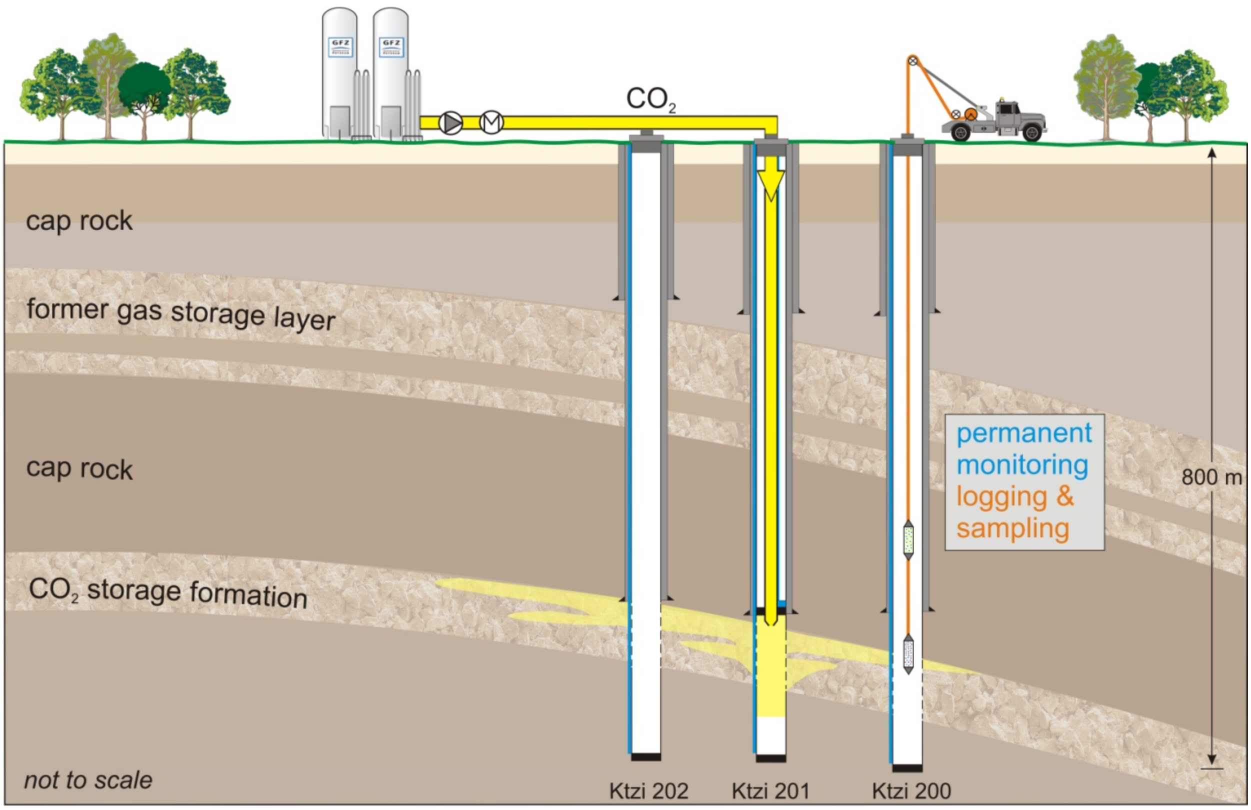

Figure 3 Schematic profile of the Ketzin CO_2 storage site.

3.1 Well Monitoring

Gas Monitoring

Permanent in-situ monitoring of CO_2 arrival and gas composition with a gas membrane sensor (GMS) has proven its functionality at both observation wells with a high temporal resolution [6]. The GMS system detected the arrival of CO_2 at the first observation well (Ktzi 200; 50 m lateral distance to the injection well) after about 530 tons of injected CO_2 on July 15, 2008. Arrival at the second observation well (Ktzi 202, 112 m lateral distance to the injection well) was recorded after about 11,000 tons of injected CO_2 on March 21, 2009.

In March 2010, the GMS in observation well Ktzi 200 has been replaced by a 6 mm stainless steel riser tubing (Fig. 4) installed down to a depth of 640 m. The in situ pressure pushes the gas through the tubing up to the surface, where it is analyzed by a mass spectrometer. With a flow rate of 8 litres/minute, the elapsed time from the gas entrance at depth until analyses at the surface is about 90 minutes. With this installation, the arrival of a Krypton tracer that was injected at well Ktzi 201was successfully detected after 800 further tons of injected CO_2.

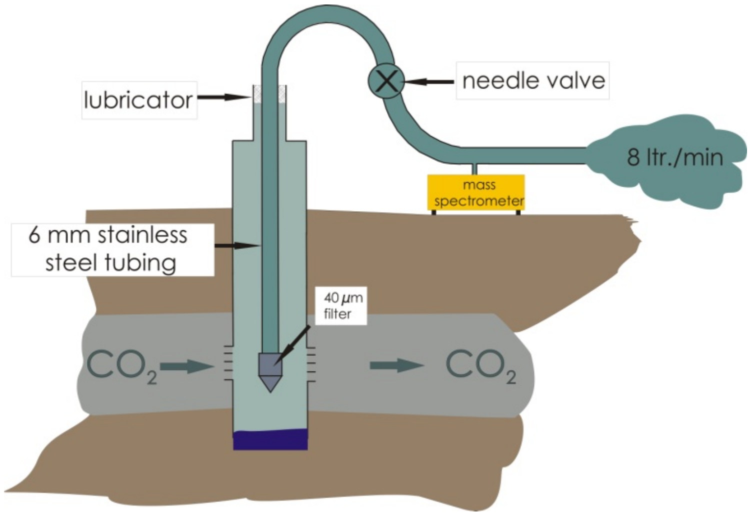

Figure 4 Sketch of the riser tubing installation at observation well Ktzi 200.

Pressure-Temperature Monitoring

Characterization of the temperature conditions in all three wells at Ketzin is done by distributed temperature sensing (DTS). The evolution of temperature in the injection interval, the arrival of CO_2 and the evolution of two-phase P/T conditions (heat-pipe effect) in the two observation wells was monitored [7]. Three DTPS (distributed thermal perturbation sensing) measurements were carried out in collaboration with the Lawrence Berkeley National Laboratory in March, July and December 2009. A strong overprint of transient temperature effects from injection was observed, resulting in a distortion of the inverted thermal conductivity profiles. Further processing and correction of the data is ongoing. The P/T gauge located at the end of the injection string in well Ktzi 201 has provided continuous pressure data through all phases of CO_2 injection (steady-state phases, stop and start-up phases) since June 2008. The permanent pressure data contributed to the safety monitoring of the CO_2 injection facility and the operational reservoir management.

3.2 Geophysical Monitoring

Seismic and geoelectric methods have been applied at Ketzin to monitor the developing CO_2 plume. Further data integration and joint interpretation of seismic and geoelectric data, also taking into account logging and modeling results, are underway to develop an approach for a quantitative estimate of the stored CO_2 volume. The present status of the geophysical monitoring can be summarized as follows:

Seismic Monitoring

Seismic baseline characterization was carried out in 2005 [8] and 2007 by cross-hole tomography between both observation wells, surface-downhole observations (MSP, VSP), and 2D and 3D surface surveys in order to cover the near-injection to regional scale. In summer and autumn 2009, measurements were repeated, providing a multi-scale view on the time-lapse effect of more than 20,000 tons of injected CO_2 [9, 10]. The cross-hole tomography revealed a significant reduction of seismic velocity within the injection horizon, while MSP and surface reflection surveys both revealed an increased reflectivity at the top of the Stuttgart Formation near the injection location. These changes in seismic properties are attributed to the CO_2 migration in the reservoir.

The 3D repeat was used to calculate the time-lapse effect on the reflection amplitude variation at the top of the Stuttgart Formation (Fig. 5). Data are scaled to the baseline reflection amplitudes of the so-called K2-horizon. This K2-horizon is an anhydritic layer of approximately 20 m thickness at the top of the cap rock. It is persistent throughout the whole area of investigation and characterized by a strong impedance contrast relative to the surrounding formations [8]. The strongest time-lapse effects are concentrated around the injection well. The migration of the injected CO_2 shows an inhomogeneous pattern indicating that the lateral heterogeneity of the Stuttgart Formation strongly affects the plume geometry. Future work will concentrate on attempts to quantify the amount of CO_2 imaged by the time-lapse seismic measurements and on matching the observations with process modeling.

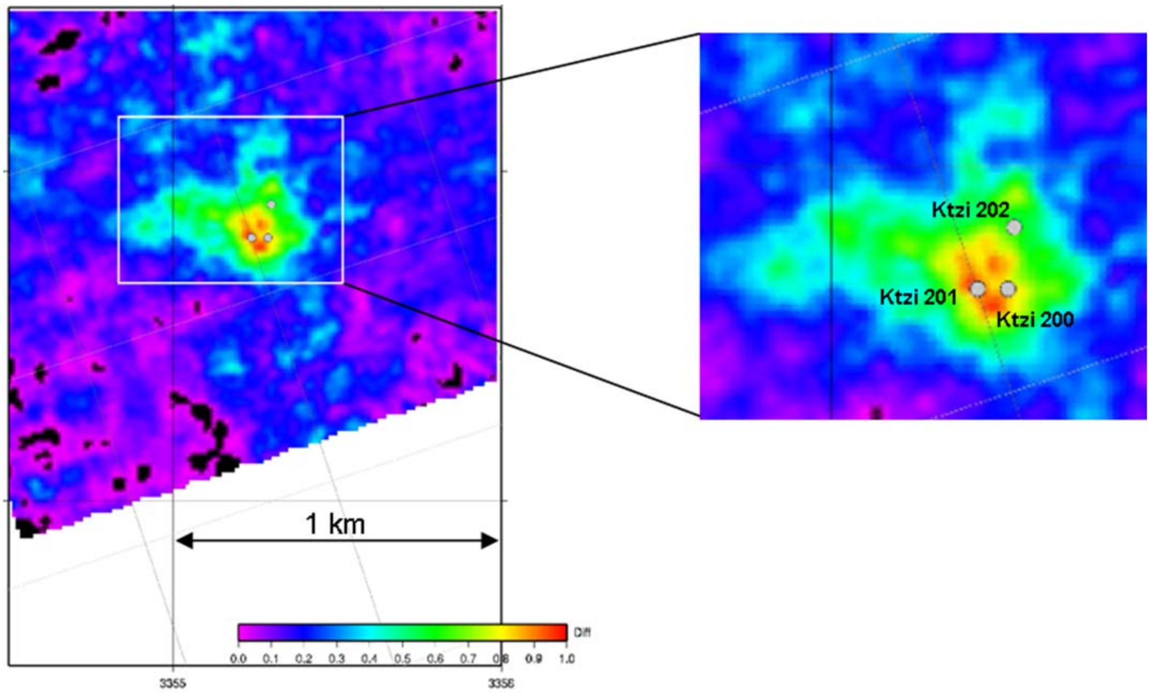

Figure 5 Map view of the normalized amplitude variation between 3D baseline (before injection) and 3D repeat (after ~14 months of CO_2 injection, [7]). Grey dots indicate the location of the injection and observation wells. High values indicating relatively strong time-lapse amplitudes are concentrated near the injection.

Geoelectrical Monitoring

Geoelectrical monitoring at Ketzin includes cross-hole measurements using the permanently installed vertical electrical resistivity array (VERA), consisting of 15 electrodes in each well, and additional surface and surface-downhole electrical resistivity tomography (ERT) [11]. The latter uses non-permanent geoelectrical dipoles at the surface (arranged in two concentric circles around the wells, with radii of 800 m and 1,500 m, respectively) in order to enlarge the observation area around the wells. Whereas cross-hole measurements were conducted on a daily (until the start of injection) to weekly basis (since March 2009), surface-downhole measurements were carried out on an intermittent basis. Investigations in the pre-injection phase included baseline measurements in October 2007 and

April 2008. Since injection began, three sets of repeat measurements were conducted in July 2008, November 2008 and April 2009 [11].

Both cross-hole and surface-downhole surveys are shown to be sensitive to changes in electrical resistivity caused by the CO_2 migration within the reservoir (Fig. 6). Both surveying methods image a significant resistivity increase in the vicinity of the injection well Ktzi 201, which extends towards the observation well Ktzi 200 with diminishing amplitude. Since both surveying methods utilize different acquisition geometries, the signatures of resistivity increase do not show complete spatial correlation. During data processing, the incorporation of data-driven error weights into the inversion was found to be important [12]. Furthermore, the inclusion of geological constraints is needed to overcome sparsity of data information density, present in the far wellbore surroundings.

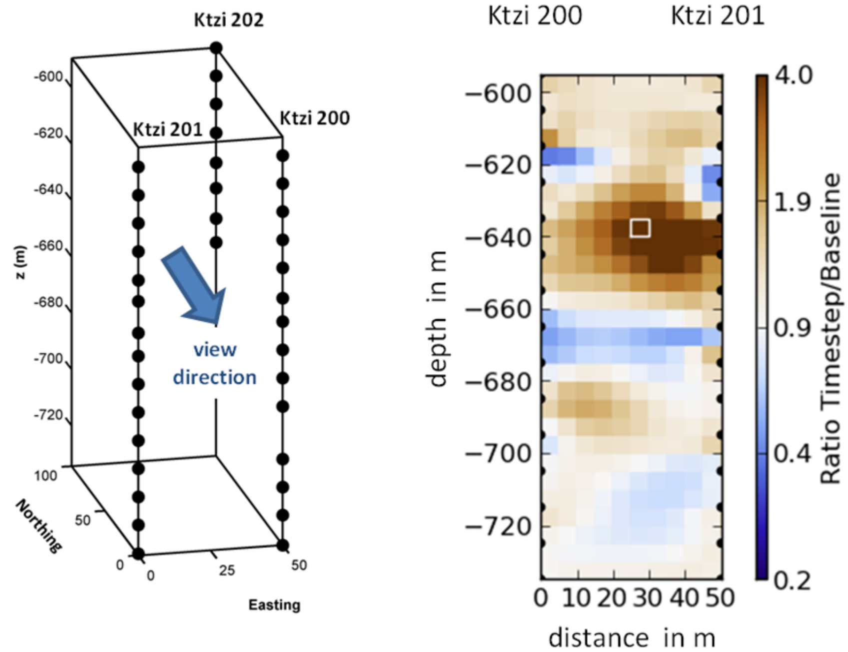

Figure 6 Resistivity ratio (2nd repeat vs. 2nd baseline) of cross-hole measurements (right), drawn as a slice through the plane of wells Ktzi 201-Ktzi 200 (left) in the depth range 590-740 m.

3.3 Microbiological and Geochemical Monitoring

The microbiological and geochemical processes in the injection and observation wells are monitored through the sampling and analyses of downhole fluid samples from all three wells [13].

Microbiologic investigation of the downhole samples using PCR-SSCP (Polymerase Chain Reaction - Single-Strand-Conformation Polymorphism) and FISH (Fluorescence in-situ hybridization) revealed that the microbial community was initially dominated by Proteobacteria, Firmicutes, halophilic anaerobic fermenting bacteria and sulphate reducing bacteria. Quantitative analysis using FISH revealed high cell numbers with up to 10^7 - 10^8 cells ml^{-1} in the injection well after one year of CO_2 injection. After the arrival of CO_2 at the observation well Ktzi 200, changes in the microbial community from chemoorganotrophic to chemolithotrophic populations, as evidenced by the temporarily out competition of sulphate reducing bacteria by methanogenic Archaea, have been observed [14].

The analyses of organic compounds in the fluid samples from the observation wells using ion chromatography revealed mainly the presence of formate and acetate. Those low molecular weight organic acids (LMWOA) represent the substrates and intermediate products of microbial metabolisms. Since injection started, the chemical composition of the formation fluids show no clear trend concerning the evaluation of the quantitative and qualitative composition of LMWOAs, but acetate was always the major constituent of LMWOA in the fluid samples [15].

3.4 Dynamic Flow Modeling

Geological modeling and dynamic flow modeling for the Ketzin site was conducted in different phases, e.g. incorporating pre-existing data, new information obtained during drilling of the three wells and subsequent CO_2 injection. Models were further refined when monitoring data, such as CO_2 arrival times at the two observation wells, became available. ECLIPSE 100, ECLIPSE 300 and MUFTE_UG were used for predicting the CO_2 arrival times at both observation wells assuming a constant injection rate, as well as for subsequent history matching with real injection data [16]. CO_2 arrival at observation well Ktzi 200 was in good agreement with all predictions made with the various modeling approaches. The calculated arrival times exceeded the real arrival times by a maximum of 18%. However, the arrival of CO_2 at observation well Ktzi 202 was notably later than predicted; the real arrival time at well Ktzi 202 exceeded the calculated ones by 300%. Potential reasons for the discrepancy between predicted and observed arrival times, namely uncertainties related to the geological model, are under further investigation. Additional modeling studies have showed that heterogeneities on a structural geological scale (low permeability barrier between wells Ktzi 201 and Ktzi 202) are one reasonable explanation for the late arrival at well Ktzi 202. However, further modeling is underway that also integrates recent geophysical monitoring data in order to improve the understanding of geological heterogeneities at the Ketzin site and their impact on the CO_2 plume distribution.

4. Conclusion and Outlook

The Ketzin project has thus far been the only active CO_2 storage site in Germany with a high national and international interest. The CO_2SINK project, as well as nationally funded projects, provided an excellent base for the establishment of reliable infrastructure for CO_2 injection and comprehensive on-site research activities. The Ketzin project has demonstrated successful CO_2 storage and monitoring in a saline aquifer on a research scale.

Based on the outcome of the previous projects, it is intended to continue the injection with complementary monitoring technologies and a particular focus on the abandonment of the test site. Two new projects CO_2MAN (CO_2 Reservoir Management with funding from the Federal Ministry of Education and Research) and CO_2CARE (CO_2 Site Closure Assessment Research, funded by the European Commission - FP 7) are planned to succeed CO_2SINK and the additional national projects which so far have funded the R&D activities at Ketzin.

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