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Inverse modelling of hydraulic testing to revise the static reservoir model of the Stuttgart Formation at the Ketzin pilot site

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Abstract

Pilot-scale CO_2 storage has been performed at the Ketzin pilot site in Germany from 2007 to 2013 with about 67 kt of CO_2 injected into the Upper Triassic Stuttgart Formation, focussing on efficient monitoring and long-term prediction strategies. We employed inverse modelling to revise the latest static geological reservoir model, considering bottomhole well pressures observed during hydraulic testing. Simulation results exhibit very good agreement with the observations, providing one reasonable permeability realization for the Ketzin pilot site near-well area. Furthermore, an existing hypothesis on the presence of a low-thickness sandstone channel between two wells is supported by our findings.

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Keywords: Geological model revision; Inverse modelling; Hydraulic testing; Bottomhole pressure; Ketzin pilot site; CO_2 storage

1. Introduction

CO_2 storage has been performed at the Ketzin pilot site in Germany from 2007 to 2013 with about 67 kt of CO_2 injected into the Upper Triassic Stuttgart Formation at 620-650 m depth to investigate efficient strategies to monitor and predict long-term CO_2 behaviour in the storage reservoir [1–6]. Static geological modelling and numerical simulations accompany these efforts since their very beginning [7–15], with a static geological reservoir model that has been developed, revised and matched against field observations to allow for predictions over short- to long-term periods [12, 16–19]. In this context, the static geological model has been continuously further developed and updated with the availability of new field data. Furthermore, many efforts have been undertaken to integrate field observations and laboratory experiments with numerical simulations [10, 12, 17, 18, 20–29], especially considering the four 3D seismic campaigns carried out at the Ketzin pilot site [30–35].

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The present study aims at validation of the latest revised reservoir model [11, 13] against bottomhole pressure data recorded during hydraulic testing of the Stuttgart Formation, undertaken after drilling the wells Ktzi 200, Ktzi 201 and Ktzi 202. Further, we employ high-performance inverse modelling to revise the static reservoir model by calibrating the spatial permeability distribution by means of the field observations made during the hydraulic tests. Our simulation results are then discussed in the context of previous findings [36–39].

2. Numerical forward model implementation

Implementation of the numerical model is based on the latest revised static geological model [11, 13], with parameters upscaled to a new simulation grid using the Petrel software package [40]. Local grid refinements (LGRs) are introduced to increase the resolution in the near-well area (6-8 m element edge lengths in horizontal direction), while the remaining grid is relatively coarse (about 90 m element edge lengths in horizontal direction, Fig. 1). Introducing nested LGRs allowed us to reduce the number of grid elements to 102,336, resulting in acceptable computational efforts in view of inverse modelling and meeting the required accuracy of the simulation results.

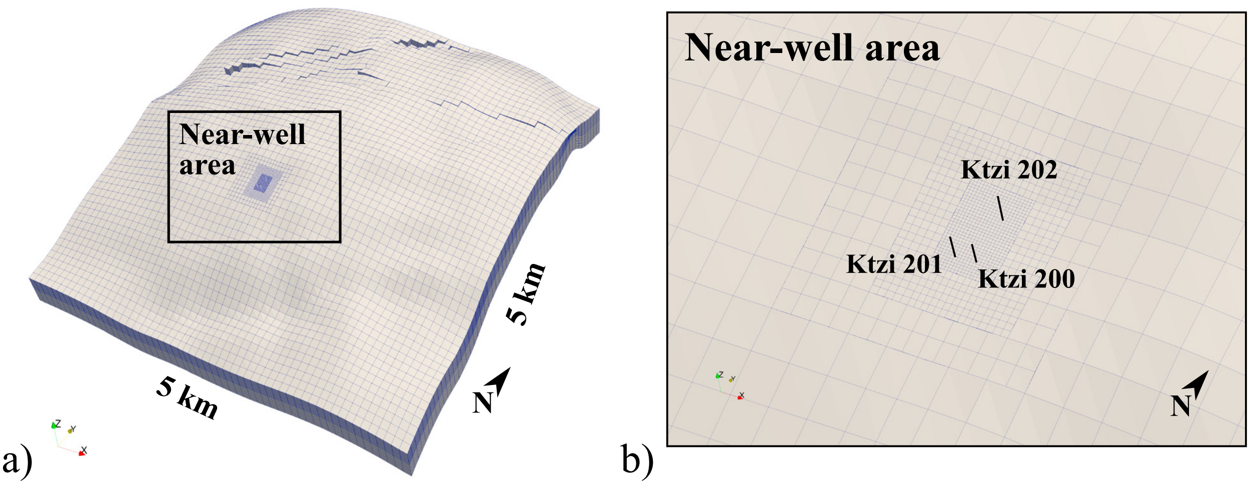

Fig. 1. Revised reservoir model grid with 102,366 elements and LGRs (a). Close-up view of near-well area, showing well locations and nested LGR structure (b). Distance between Ktzi 201 and Ktzi 200 is 50 m.

The BLACKOIL module of the scientific numerical simulator MUFITS [41, 42] is used in the present study, whereby previously undertaken benchmark simulations demonstrate that simulation results, absolutely identical to those produced with a standard industry simulator, can be achieved even over a long-period simulation of CO_2 injection at the Ketzin pilot site [42]. The interested reader is kindly referred to Kempka et al. [9, 11], Kempka and Kühn [10] and Class et al. [43] for detailed information on the numerical multiphase flow model parametrization and its impacts on the simulation results.

3. Static reservoir model validation against hydraulic testing data

We employed the bottomhole pressures and fluid flow rates recorded during hydraulic testing at the Ketzin pilot site [36, 38] to investigate the response of the static reservoir model revision presented by Kempka et al. [11]. Flow rates as well as observed and simulated bottomhole pressures are shown in Fig. 2.

Simulated pressure drawdown in any of the wells is about one order in magnitude below the observed bottomhole data, indicating that reservoir permeabilities assigned in the static reservoir model are not representing those in the Stuttgart Formation. This is confirmed by a hydraulic testing interpretation [36], previous simulations using the hydraulic testing data [37, 38], and the permeability multipliers required to match the bottomhole pressure history using the revised model [10, 11, 43]. The authors of the latter studies found that permeability reductions by factors of 0.05