The Atzbach-Schwanenstadt gas field – a potential site for onshore CO_2-storage and EGR

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Abstract
Atzbach-Schwanenstadt gas field in Upper Austria, operated by Rohöl-Aufsuchungs AG, is a potential storage site for CO_2. In order to quantify amount of CO_2 that can be stored in the reservoir, a geological model has been made on which a simulation model was based.
Based on observed production data, estimates of reservoir capacity have been made. As much as 3.2 million tonnes of CO_2 produced by industry could be stored in the reservoir. Also a potential for enhanced gas recovery process has been estimated. Preliminary reservoir simulation calculations show that Atzbach-Schwanenstadt reservoir could be a good CO_2 storage site.
Atzbach-Schwanenstadt is a natural gas reservoir therefore it is expected that it would be also safe in respect to potential leakage of CO_2. Safe containment of CO_2 should occur if reservoir pressure will stay below initial pressure. Additionally the integrity of wells in the field is important for safe storage of CO_2.

Keywords: CO_2 storage, Atzbach-Schwanenstadt, EGR

Introduction and methodology
As a part of the EU-funded CASTOR project [1], four sites for potential or actual underground CO_2 storage in Europe are being investigated. One of these sites is the Atzbach-Schwanenstadt gas field in Upper Austria, operated by Rohöl-Aufsuchungs AG. The CASTOR project is a feasibility study with the aims:

- to estimate CO_2 storage capacity of the sites,
- to assess which infrastructure might be necessary (especially, how many injection wells),
- to evaluate if positive effects of CO_2 injection on gas production are likely,
- to asses if the site is likely to be safe.

The Atzbach-Schwanenstadt gas field is situated in the Molasse Basin in the foreland of the Alpine mountain chain, outside the area affected by compressional deformation. Its reservoir formations are part of the Puchkirchen Basin a deepwater trough parallel to the alpine front.
Potential CO_2 sources are a paper mill (emitting about 200 000 tonnes of CO_2 per year) and a fertiliser plant (emitting about 100 000 tonnes of CO_2 per year). Transport of CO_2 may be by trucks.
Site assessment in the Atzbach-Schwanenstadt case includes the following components:

a) Construction of a digital geological model based on horizon, fault and facies interpretation in 3D seismic data (partial coverage of the field) and 2D seismic lines, stratigraphic pick interpretation in 50 wells and petrophysical interpretation of wire-line logs in 8 wells.
b) Construction of an upscaled reservoir model based on core measurements and the digital geomodel; history matching against documented gas production and monitored downhole pressure.
c) Reservoir simulations to assess the quantity of CO_2 that can be injected, to plan an efficient injection pattern, and to evaluate the potential for enhanced gas recovery (EGR).
d) Soil gas measurements to provide background data for future soil gas monitoring.
e) A feasibility study to assess the possibilities for seismic monitoring of the potential injection program.
f) Geochemical experiments and simulations to help predict the effect of CO_2-rich brine on the seal material.
g) Geomechanical experiments and simulations to assess the effect of CO_2 on the mechanical stability of the site.
h) Analysis of available data on the wells in the field with respect to their pressure integrity.
i) Long-term simulations and integrated risk analysis.

This paper focuses on activities a) to e).

Geological model

The digital geomodel ranges from the base of the Hall Series (Miocene) to the Top Eocene, with a special focus on the main reservoir zone (Zone "A4") of the Upper Puchkirchen Series (Oligocene to Miocene). Recently, merged 3D seismic data with regional coverage enabled a re-interpretation of the depositional environment for the deepwater sequence in the Puchkirchen trough [2] as a meandering submarine channel system, sourced from the west and extending along the east-west striking basin axis.

The Atzbach-Schwanenstadt field contains producible gas in the Upper Puchkirchen Series (mainly in the A4 sub-unit) and some smaller volume in the basal Hall Series. The sandy parts of the Upper and Lower Puchkirchen Series in the field have been chosen as the main target for potential CO_2 injection. The basal Hall Series and the sand bodies at the base of the upper Hall Series may serve as auxiliary reservoirs to store any CO_2 which might leak through the immediate seal, constituted by the mudstone sequence between the A4 unit and the base of Hall Series. The upper part of the Hall Series, consisting of approximately 600 to 800 m of mudstone-dominated sediments, forms the upper seal for the potential storage site. The top of the main reservoir zone A4 is at approximately 1600 m below surface while the base of the Hall Series is at approximately 1100 m below surface.

The gas-bearing sandstones consist of many thin layers (one to a few dm in thickness), separated by shale layers of similar thickness. The sandstone connectivity is unclear. The facies with the best reservoir properties are levee and splay deposits, while porosity of central channel deposits is as low as that of the background facies.

Channels, levee and splay deposits were mapped on seismic where they appear as high-amplitude reflectors (Figure 1). These mapped zones were used to guide facies modelling in Petrel. The channels and levees were modelled as discrete bodies, while the splay deposits were modelled in a probabilistic way conditioned to seismic amplitudes and to interpreted facies in wells. Reservoir properties (especially porosity and permeability) were stochastically assigned, conditioned by their occurrence in the wells with petrophysical interpretation and by their statistical distribution in the various facies.

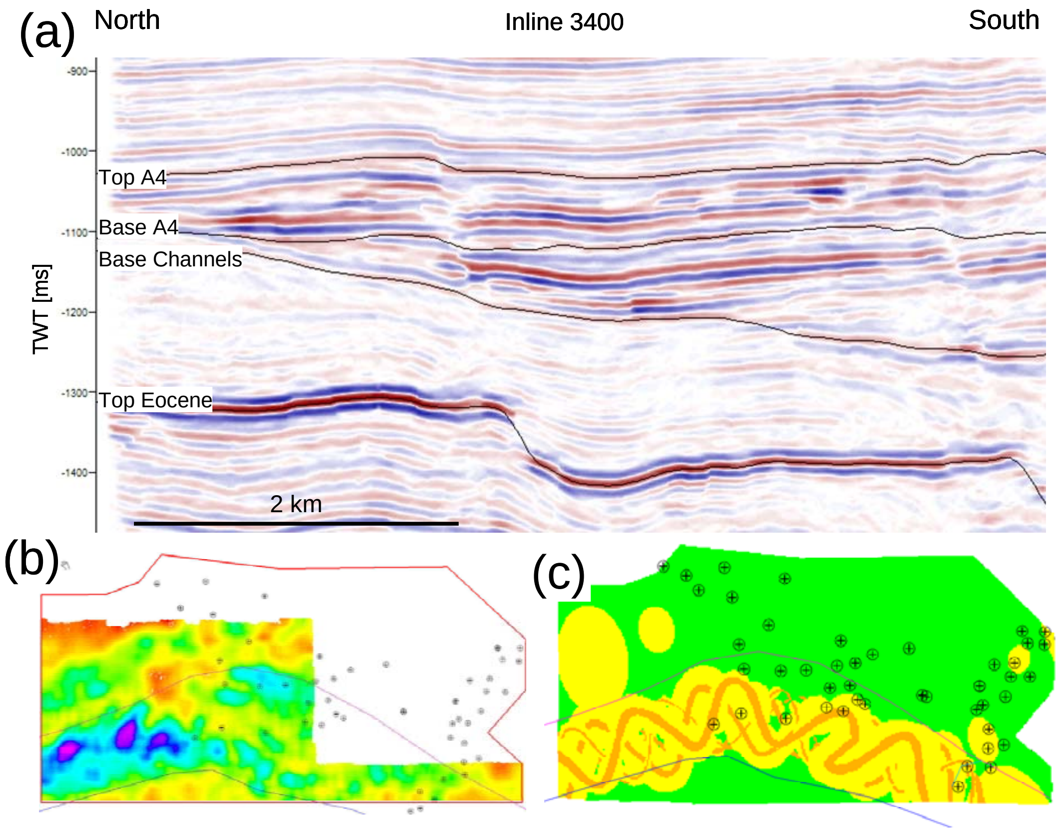

Figure 1 Seismic amplitudes interpreted to signify channel, levee and overbank facies (a, b; white area in b was covered by 2D seismic data not shown here) were used to generate facies maps for several reservoir layers (c; orange: channel; yellow: levee and splay; green: background sedimentation).

Reservoir model

The reservoir model (Figure 2) focuses on the A4 zone and includes only the central part of the field, where gas productivity is best and where a relatively uniform gas-water contact exists. Reservoir parameters were upscaled from the geomodel to yield a model size that enables fast simulations. Analysis of production data (particularly the pressure draw-down pattern) indicates a compartmentalization of the field also in its central part, however, the constant gas-water contact suggests that this compartmentalization is not complete, but is restricted to effects on production time-scale. It is likely to affect the CO_2-injection, too. The almost complete lack of water production in spite of the closeness of water to the perforated intervals in many wells indicates that water in the gas zone is largely immobile. The overall pressure draw-down shows that the reservoir has no aquifer support.

As a consequence of these observations, it is expected that injected CO_2 will during the potential injection period only be able to replace previously produced gas in the reservoir. Formation water can in the simulations be treated as immobile. The porosity of the favourable sandstone layers ranges from 10 % to 22 % with permeabilities ranging from 1 mD to 200 mD. Entry pressures are very low (approx. 5 kPa for CO_2), residual (connate) water is around 15%. Net-to-gross ratio varies from 0.10 in the western part of the reservoir up to 0.90 in the eastern part.

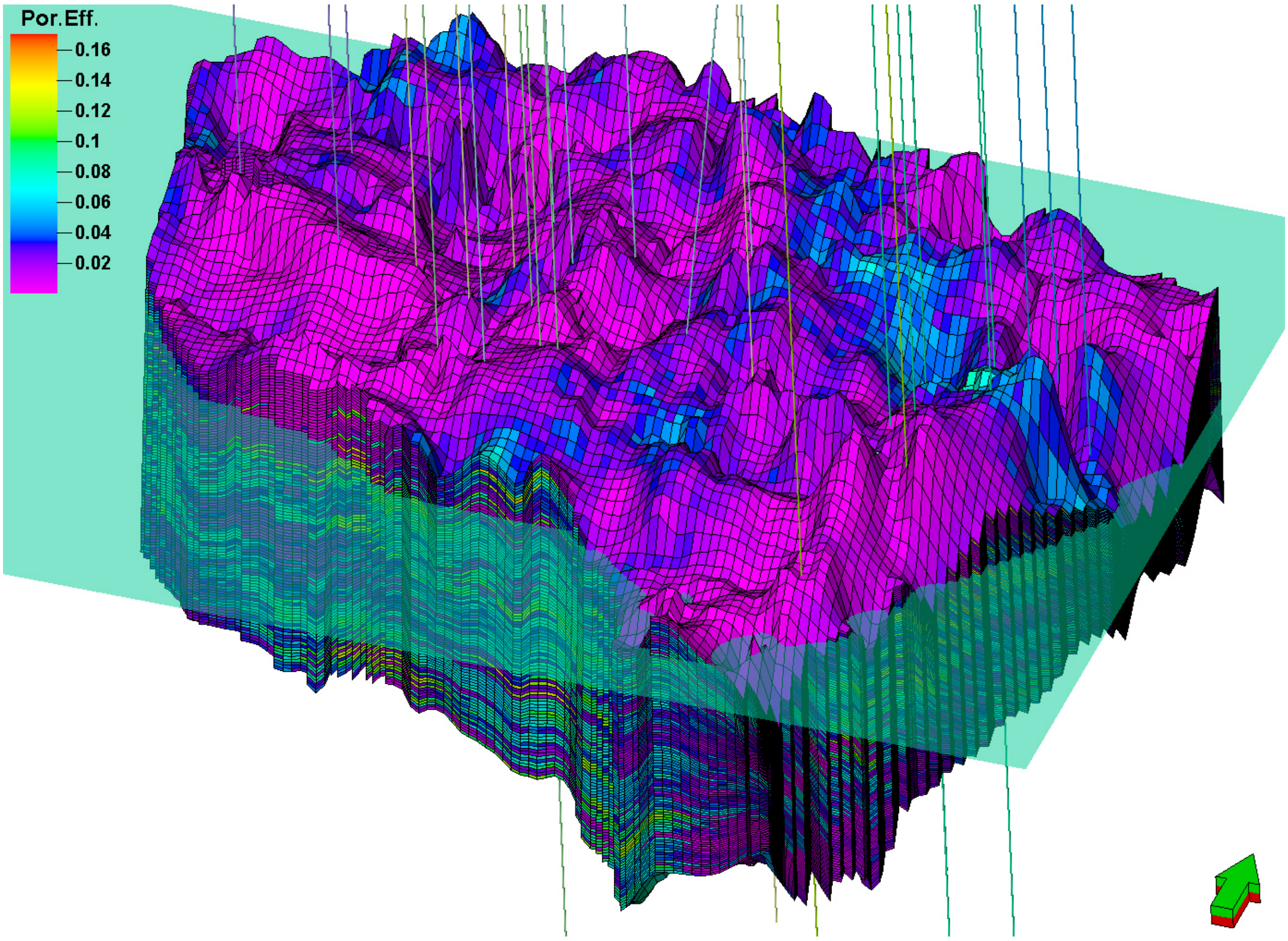

Figure 2 Simulation model and production wells; colour scale represents effective porosity; green transparent plane shows gas-water contact at 1210 mss; Z-scale exaggerated 20x

CO_2 injection and EGR

Estimated initial gas in place in A4 zone of the Atzbach-Schwanenstadt gas field is $3.81 \cdot 10^9$ Sm^3 of which $3.45 \cdot 10^9$ Sm^3 have been already produced. Assuming that injected CO_2 can replace all produced gas then this corresponds to a storage capacity of 3.2 million tonnes of CO_2.

It is expected that paper mill and fertilizer plant together can deliver 300 000 tonnes of CO_2 per year. In respect to the available storage capacity, injection with an assumed maximal rate of 300 000 tonnes/year could then last for around 11 years. This gives a daily injection rate of approx. 440 000 Sm^3 which can be injected using only one injection well. However if EGR is going to be applied then several injection wells should be considered in order to make the EGR process more efficient. Proposed well pattern scenario is shown in Figure 3. Old production wells can be used as injectors and wells in which gas production ceased completely were chosen. Injected CO_2 would sweep the remaining gas in the reservoir towards production wells. When CO_2 breakthrough occurs it can be reinjected back into the reservoir. CO_2 could be injected simultaneously into all proposed wells but the final solution depends on economical and technical issues.

In order to avoid risk of causing possible reservoir seal fracturing and consequently CO_2 leakage, it is recommended to keep reservoir pressure during injection period below the initial reservoir pressure of 160 bars.

It is also required that abandoned wells are monitored in order to verify their integrity and report any changes at any point in time.

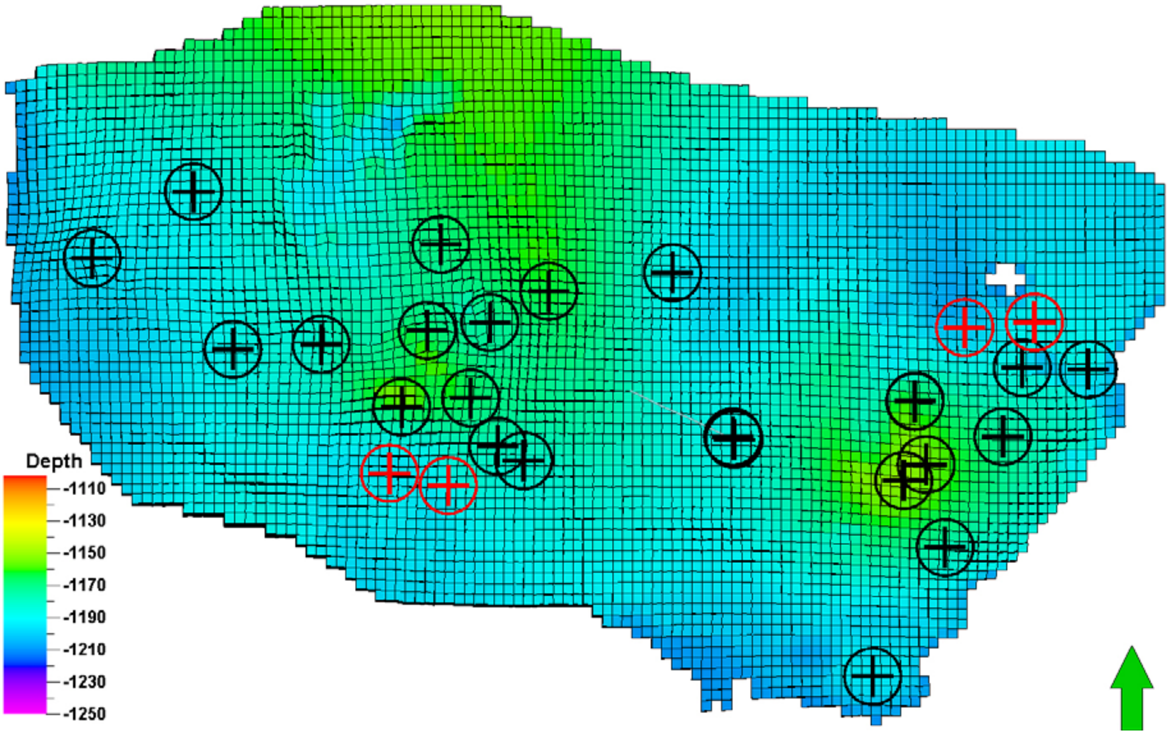

Figure 3 Depth map of the top of the reservoir and all gas production wells; wells marked red show proposed production wells that could be converted into CO_2 injection wells; grid block size is 100x100m

Seal properties

The seal is formed by a >500m thick, essentially unfaulted overburden of Miocene mudstones and tight siltstones. The cap rocks contain TOC contents of 0.3 to 0.9%. The organic material is mainly of terrestrial origin (kerogen type III) and less sensitive against extraction by supercritical CO_2. Diffusion experiments revealed very low diffusion coefficients of approximately 10^{-11} m^2/s which indicates that diffusion would play a minor role for potential leakage. Single phase (brine) permeability of the seal samples ranges from $6.5 \cdot 10^{-20}$ m^2 to $1 \cdot 10^{-21}$ m^2 (65 to 1 nD). The residual pressure according to the method of Hildenbrand et al. [3] [4] is for the seal samples approximately 7 MPa to 9 MPa. This pressure is approximately 0.3 to 0.5 of the breakthrough pressure for capillary leakage [5] and would correspond to a non-leaking CO_2-column height of approx. 5 km to 10 km.

Baseline CO_2 soil gas monitoring

Since 2004 a baseline monitoring campaign for CO_2 soil gas fluxes is being carried out. Up to now, this campaign delivered areal information about the present-day CO_2 fluxes, and its seasonal and diurnal variations. CO_2 soil gas fluxes of up to 80 g/day/m^2 have been recorded (Figure 4). However, these data change with location and type of soil, and are dependent on season and soil humidity. Carbon isotopes of CO_2 indicate that CO_2 soil gas is derived from three sources: a. penetration of atmospheric CO_2 into permeable soil horizons, b. bacterial decomposition of soil organic matter, and c. oxidation of soil gas methane.

A special focus is on the methane fluxes above the field, the origin (soil gas formation vs. gas from the reservoir) and geological factors (potentially increased fluxes above tectonic elements). For this purpose, soil gas samples across the whole field are screened for composition and bacterial overprint within the soil profile (e.g. anaerobic methane oxidation).

Furthermore, a gas monitoring station is installed to record minute variations of total soil gas concentrations and single CO_2 and CH_4 gas concentrations. All these data sets are analysed for meteorological, hydrogeological and seismic impacts. This station offers a powerful tool for a localized high-resolution monitoring and is recommended as "the" monitoring device for long-term observation of potential leakage phenomena.

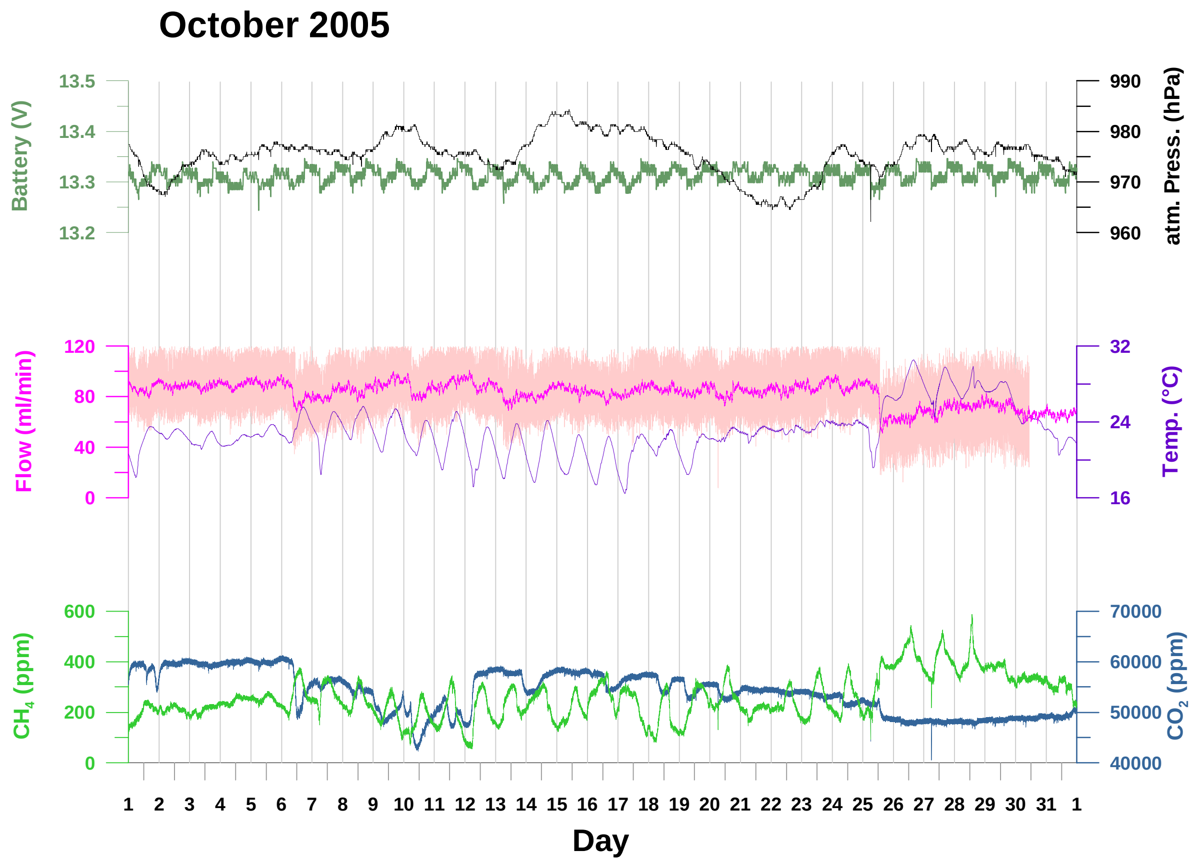

Figure 4 Data of soil gas concentrations and other parameters recorded at the monitoring station. The monitoring station is located above the eastern sector of the gas field

Conclusions

Atzbach-Schwanenstadt gas field has a promising potential for CO_2 storage. Its total available storage capacity of 3.2 million tonnes of CO_2 would be enough to store all CO_2 produced during the next 11 years by potential industrial sources (paper mill and fertilizer plant). If an EGR process would be applied it could increase gas production and enlarge available storage capacity for CO_2.

Regarding potential leakage it is expected that Atzbach-Schwanenstadt as a natural gas reservoir will be safe for CO_2 storage as long as the CO_2 injection do not cause an increase in reservoir pressure above the initial pressure. Well integrity of abandoned wells is also important for safe storage.

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