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Reservoir simulation study of CO_2 storage and CO_2-EGR in the Atzbach-Schwanenstadt gas field in Austria

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Abstract

The Atzbach-Schwanenstadt gas field has been investigated in the CASTOR project with respect to its suitability for safe, long-term underground CO_2 storage.
Storage capacity of the reservoir has been estimated to 14.5 million tonnes of CO_2. Potential nearby CO_2 sources emit together about 300 000 tonnes of CO_2 per year. Assuming that reservoir would be filled up until its initial reservoir pressure the available storage capacity would be sufficient to store all CO_2 produced during the next 48 years. Results from the reservoir simulation of the storage showed that during 30 years of injection 8.2 million tonnes of CO_2 could be stored.
A CO_2-EGR effort in the field could in theory increase gas production and therefore enlarge the available storage capacity for CO_2. However, none of the conducted reservoir simulations could prove that CO_2 injection would enhance gas recovery at the Atzbach-Schwanenstadt field. CO_2 breakthrough to the production wells is very quick and occurs almost immediately after start of injection. The fraction of CO_2 in produced gas increases rapidly and this limits production of the clean gas. Compared to the simulation with no CO_2 injection, EGR cases give lower production of the clean gas. Therefore use of CO_2 for the enhanced gas recovery is not recommended for the Atzbach-Schwanenstadt field.
The long-term storage simulation shows that reservoir pressure stabilizes shortly after injection stops. During the period of 1500 years after the end of injection only 10% of injected CO_2 will dissolve in the immobile reservoir water.
In a scenario of potential leakage four abandoned wells were selected to mimic leaking wells. Simulation results show that if CO_2 reaches the abandoned wells, and this would lead to leakage, as much as 5.6% of injected CO_2 could escape from the reservoir during a period of 1500 years.

Keywords: CO_2 storage; CASTOR; Atzbach-Schwanenstadt; Reservoir Simulation; Long-term simulation

1. Introduction

As one of four case studies, the Atzbach-Schwanenstadt gas field, located in Upper Austria and operated by Rohöl-Aufsuchungs AG (RAG), has been investigated in the CASTOR project with respect to its suitability for safe,

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long-term underground CO_2 storage. This paper presents results of the reservoir simulations of short and long term CO_2 injection predictions as well as evaluation of potential for enhanced gas recovery (EGR).

2. Methodology

All simulations were performed using the compositional simulator Eclipse 300. An eight-component description (including CO_2) is used for the reservoir gas. Petrel software was used for construction of the geological model, data integration, history matching analysis and results visualization of the CO_2 injection simulations.

3. Input data

In order to quantify the amount of CO_2 that can be stored in the reservoir, a geological model of the area has been made [1] on which a simulation model was based. The digital geological model ranges from the base of Hall Formation (Miocene) to upper Eocene (Figure 4.1.a), with a special focus on the main reservoir zone of the Upper Puchkirchen Formation (from Oligocene to Miocene) [1]. The reservoir simulation model focuses on the zone A4 (Figure 4.1.b) which includes only the central part of the field, where gas productivity is best and a relatively uniform gas-water contact exists. The top of the reservoir is limited by the 'gas-top' surface (Figure 4.1.b). This surface is constructed from the well observation of the uppermost occurrence of the hydrocarbon gas in wells [2].

4. History matching simulation

Production from the field started in 1963 and this was also the start of the history matching simulation. The last production report used in the simulation was from December 2006. Since the field is still in production it has been assumed that reservoir simulation should continue until 2010 before possible CO_2 injection could take place. There were 28 wells producing during the history of the field. The volume of the gas initially in place (GIIP) provided by RAG was estimated to be 4 353 million Sm^3. The total observed field gas production by December 2006 was 3 666 million Sm^3 [3].

The input parameter used for the history matching was the observed gas production in the wells. In the history matching the intention was to obtain a match of the GIIP and wells bottom hole pressure (BHP). Due to the fact that water in the reservoir was highly immobile the volume of produced water was negligibly small. Therefore water production was not taken into consideration in the history matching.

Since the reservoir boundaries are not exactly defined in the geological model the reservoir model has been divided into two regions. For the GIIP calculation the Region 1 indicated in Figure 4.2 has been used, as suggested by RAG. The remaining part of the model – Region 2 – has been set to low permeability so any gas inflow from this part of the model to the GIIP region is negligible.

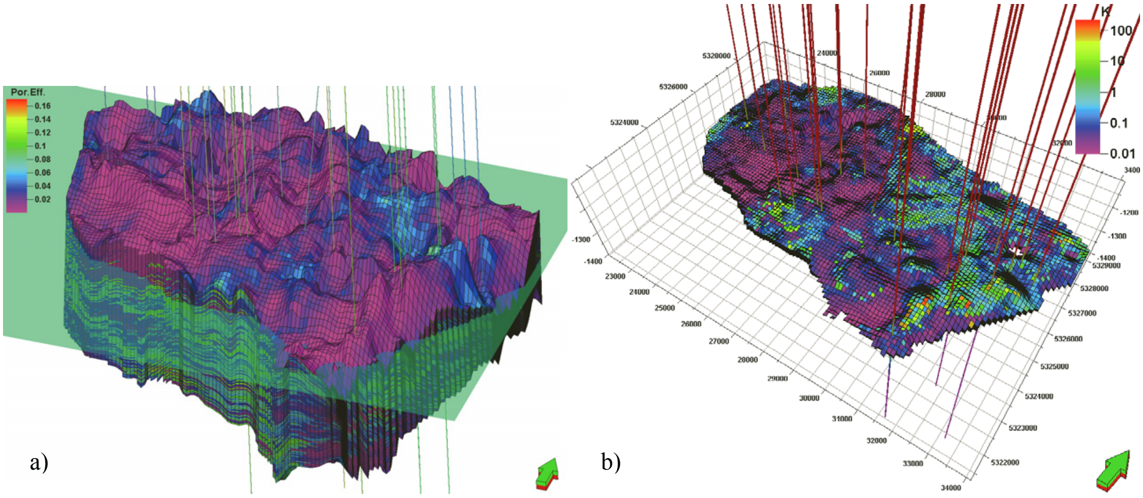

Figure 4.1. a) Effective porosity model showing the locations of producing wells in the field [2]; color scale represents effective porosity; the transparent green plane shows gas-water contact at 1210 mss; vertical exaggeration=20x. b) Simulation grid showing the A4 zone above the gas-water contact and below gas-top surface [2]; color scale represents horizontal permeability; vertical exaggeration=10x.

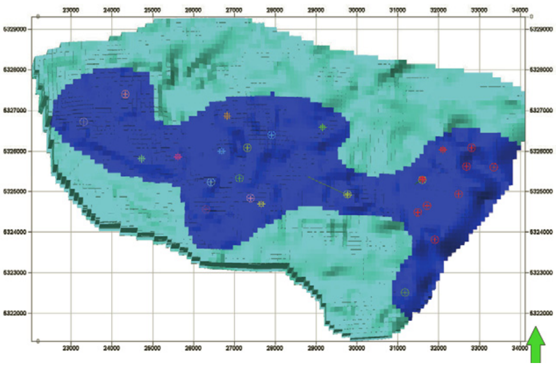

Figure 4.2. Top view of the reservoir model [2]; the dark blue area (Region 1) represents the part of the field used in GIIP calculation; the light blue area represents the low-permeability outer part (Region 2); symbols show well head location of the production wells.

5. CO_2 storage and EGR

5.1. CO_2 storage capacity

Calculation of the CO_2 storage capacity of the Atzbach-Schwanenstadt field was based on the volume of produced gas. It was estimated that pore volume available for CO_2 storage corresponds to as much as 14.5 million tonnes of CO_2. However, the actual capacity will be lower and will depend on injection rate as well as location and number of injection wells. Low permeability will limit the distribution of the CO_2 in the reservoir and therefore not all available pore space will be reached by injected CO_2.

Potential nearby CO_2 sources are a paper mill and a fertilizer plant. Combined, they emit about 300 000 tonnes of CO_2 per year, and thus the available storage capacity would be sufficient to store all CO_2 produced during the next 48 years assuming that reservoir would be filled up until its initial reservoir pressure. The reservoir storage capacity as a function of reservoir pressure is presented in Figure 5.3.

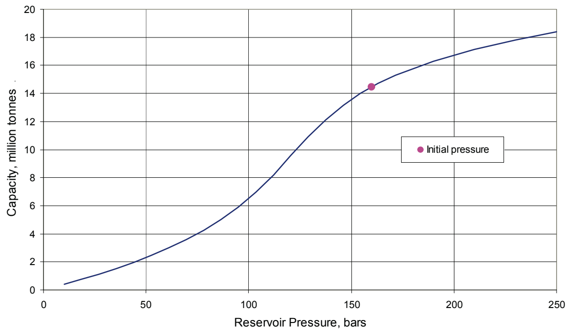

Figure 5.3. The Atzbach-Schwanenstadt CO_2 storage capacity vs. reservoir pressure.

5.2. CO_2 storage and EGR simulations

The paper mill and fertilizer plant together can deliver up to 300 000 tonnes of CO_2 per year to the site. This gives a daily injection rate of approximately 820 tonnes. This volume of CO_2 could be injected using only one injection well. However, it was assumed that pressure in the reservoir during CO_2 injection should not exceed initial reservoir pressure in order to prevent possible seal fracturing. Therefore, in order to make injection safe, the BHP limit for injection wells has been set to the initial reservoir pressure of 160 bars. Also, if the EGR is going to be applied then several injection wells should be considered in order to make the EGR process more efficient.

Four different injection scenarios were investigated, with and without EGR, and with injection into old or new wells. CO_2 injection started in 2010 in all simulation cases and it lasted 30 years.

Results from the storage base case show that 8.2 million tonnes of CO_2 could be stored during 30 years of injection (Figure 5.4.a). In this scenario, injection rates need to be reduced towards the end of the injection period in order to keep injection pressure below the initial reservoir pressure.

The goal of the EGR simulation was to find out if CO_2 injection can stimulate (increase) gas production. Re-injection of produced CO_2 was not considered. Two economic limits were set on gas production wells from 2010: 1) if the gas production falls below 525 Sm^3/day then the production well is shut (economic limit given by RAG) and 2) if the mole fraction of CO_2 in produced gas increases above 50% then well connections which exceed this limit will be shut.

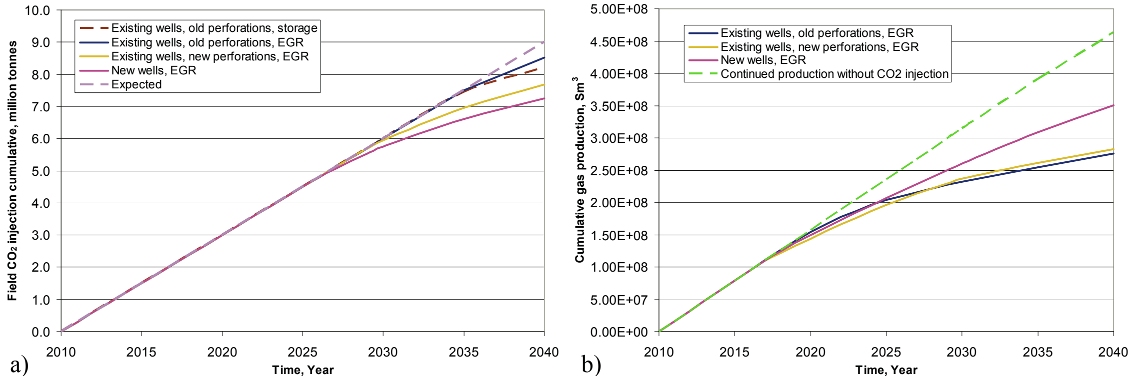

Figure 5.4. a) Field CO_2 injection cumulative; for comparison curve named 'Expected' shows cumulative CO_2 injection with rate of 300 000 tonnes per year [2]. b) Cumulative gas production after 2010 in EGR simulations and without CO_2 injection [2].

A CO_2-EGR effort in the field could in theory increase gas production and therefore enlarge the available storage capacity for CO_2. However, none of the conducted reservoir simulations could prove that CO_2 injection would enhance gas recovery at the Atzbach-Schwanenstadt field (see Figure 5.4.b). CO_2 breakthrough to the production wells is very quick and occurs almost immediately after start of injection. The fraction of CO_2 in produced gas increases rapidly and this limits production of the clean gas. Compared to the simulation with no CO_2 injection, EGR cases give lower production of the clean gas. Therefore use of CO_2 for the enhanced gas recovery is not recommended for the Atzbach-Schwanenstadt field.

6. Long term reservoir simulation

The goal of the long term reservoir simulation was to investigate fate of the CO_2 in the reservoir after completion of the storage process. The study focused on pressure changes and CO_2 concentration distribution in the reservoir. In addition to the case were CO_2 behaviour in the reservoir was tracked during the first 1500 years after injection, two hypothetical leakage scenarios have been considered. All long term simulations were continuations of the storage base case presented in chapter 5.2.

6.1. Long term storage

Due to differences in injectivity for the three injection wells (Figure 6.6), there was considerable variation in the pressure in Region 1 at the end of injection. The pressure in the compartment where well ISCH-015 is located reaches the maximum allowed pressure of 160 bar while pressure around the other two injection wells was lower. Simulation shows that after stop of injection movement of gas in the reservoir evens out this pressure variation (Figure 6.5.a). Pressure equilibration between Region 1 and Region 2 takes longer time and is still ongoing after 1500 years (Figure 6.5.a, Figure 6.6.a and b). During period of 1500 years after the end of injection only 10% (Figure 6.5.b) of the injected CO_2 will dissolve in the immobile reservoir water.

The movement of gas due to lateral pressure gradients also causes a re-distribution of the injected CO_2. A large increase in the mole fraction of CO_2 in the reservoir gas is observed in a region midway between wells IATZ-002 and ISCH-015 (Figure 6.6.c and d). After the first 500 years, when the pressure gradient almost has disappeared (Figure 6.5.a), the changes are much slower.

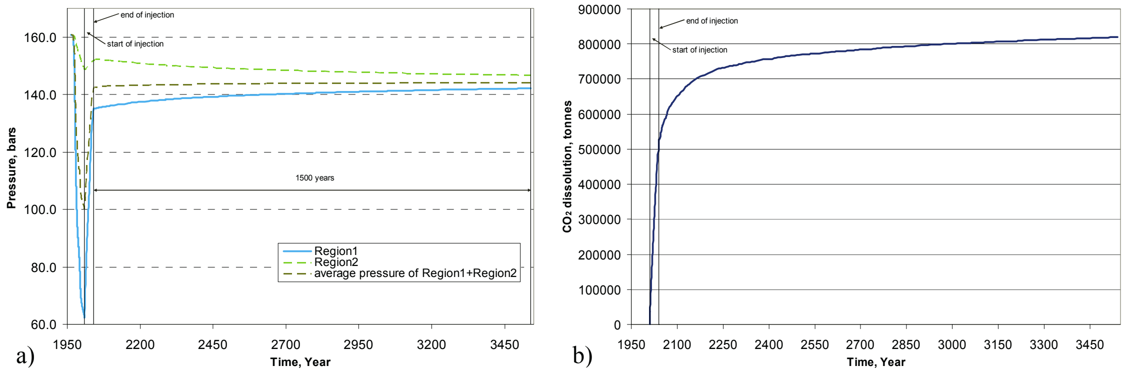

Figure 6.5. a) Reservoir pressure development during gas production, CO_2 injection and long-term CO_2 storage [4]. b) CO_2 dissolution in the reservoir water [4].

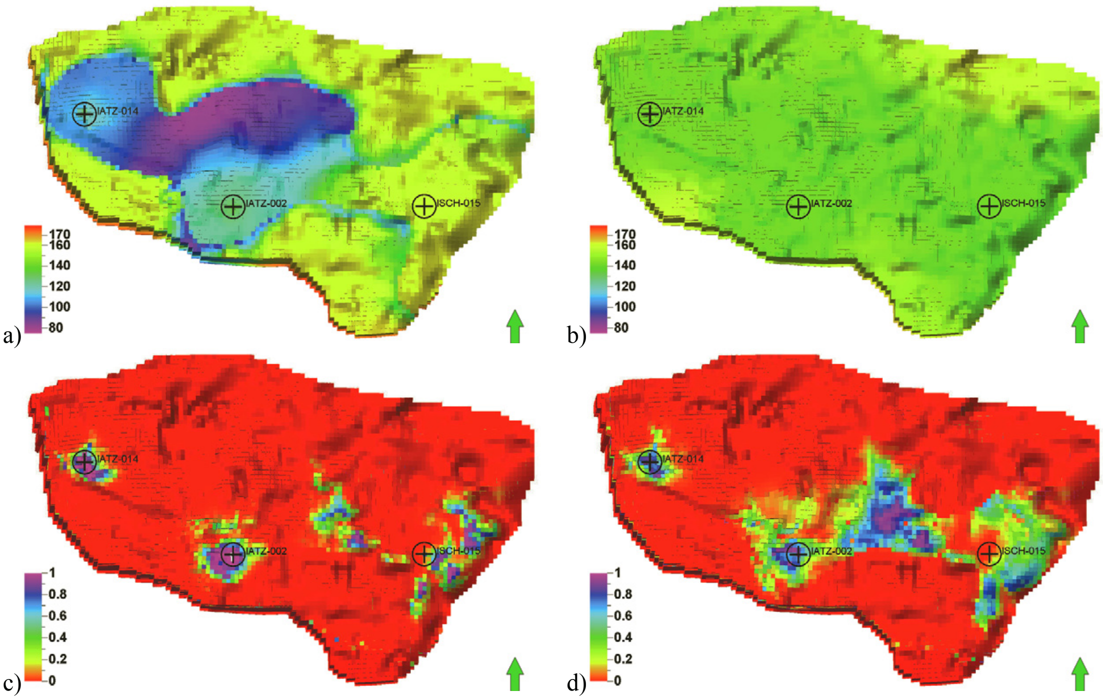

Figure 6.6. Reservoir pressure at the end of injection (a) and after 1500 years from the end of injection (b) [4]. CO_2 mole fraction distribution in the reservoir at the end of injection (c) and after 1500 years from the end of injection (d) [4].

6.2. Leakage simulations

Re-distribution of the injected CO_2 may lead to contact with wells abandoned according to regulations that do not consider exposure to CO_2. Therefore two hypothetical leakage scenarios have been investigated where such wells start leaking when the CO_2 concentration around them exceeds 10%: 1) leakage controlled by limit on BHP and rate of leaked gas and 2) leakage controlled only by limit on BHP. It is assumed that even if leakage occurs it will not be large enough to cause significant change in the reservoir pressure close to the leaking well. Thus, in the simulations BHP is not allowed to fall below 90 bars. This is close to the pressure around the four potentially leaking wells at the end of the injection period.

In the leakage scenarios it is seen that only one well, ATZ-004, is contacted by CO_2 in high enough concentrations to trigger significant leakage (Figure 6.7.a). This happens approximately 60 years after end of injection (Figure 6.7.b). This well then continues to leak throughout the studied post-injection period, with a gradually higher volume fraction of CO_2. The leaked fraction after 1500 years is approximately 5.6% of the stored CO_2 (Figure 6.7.b).

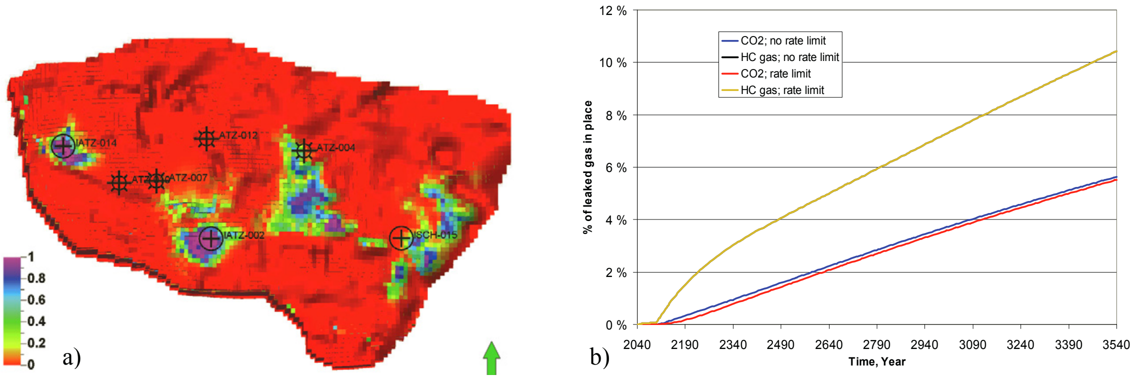

Figure 6.7. a) CO_2 mole fraction distribution in the reservoir during leakage 50 years after the end of injection [4]. b) Cumulative leakage of CO_2 and HC gas in fraction of amount present in the reservoir at the end of injection period; note that two curves for HC gas overlap each other [4].

7. Discussion and conclusions

The Atzbach-Schwanenstadt gas field offers promising potential for CO_2 storage. Its total available storage capacity of 14.5 million tons of CO_2 would be sufficient to store all CO_2 produced during the next 48 years by the nearby paper mill and fertilizer plant. However, the actual capacity will be lower and will depend on injection rate as well as location and number of injection wells. Low permeability will limit the distribution of the CO_2 in the reservoir therefore not all available pore space will be reached by injected CO_2.

A CO_2-enhanced gas recovery effort in the field could in theory increase gas production and therefore enlarge the available storage capacity for CO_2. However, none of the conducted reservoir simulations could prove that CO_2 injection would enhance gas recovery. Injected CO_2 breakthrough to the production wells is very quick and occurs almost immediately after start of injection. Content of the CO_2 in produced gas increases rapidly and this limits production of the clean gas. Compared to the simulation with no CO_2 injection, EGR cases give lower production of the clean gas. Therefore use of CO_2 for the enhanced gas recovery is not recommended for the Atzbach-Schwanenstadt field. Possibly, positive effect of the CO_2 use for EGR could be obtained after the field would become depleted and could not produce with economical rates. Then CO_2 injection would increase reservoir pressure and this could stimulate gas production. Nevertheless high contamination of produced gas by CO_2 should be expected.

Long term simulation shows that after stop of injection movement of gas in the reservoir evens out pressure variation. Pressure equilibration between Region 1 and Region 2 takes longer time and is still ongoing after 1500 years. During the period of 1500 years after the end of injection only 10% of the injected CO_2 will dissolve in the immobile reservoir water.

Regarding potential leakage, it is expected that the Atzbach-Schwanenstadt as a natural gas reservoir will be safe for CO_2 storage as long as the CO_2 injection does not increase the reservoir pressure above the initial pressure and the integrity of the wells will be kept.

In the potential leakage scenarios it is seen that only one well is contacted by CO_2 in high enough concentrations to trigger significant leakage. The simulated leakage rates would be enough to fill an average-sized house per day. Apart from this simple calculation, however, the HSE impact of the leaking CO_2 has not been investigated further in the present study.

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