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SEQUESTRATION OF CO_2 IN THE ALTMARK NATURAL GAS FIELD, GERMANY: MOBILITY CONTROL TO EXTEND ENHANCED GAS RECOVERY

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ABSTRACT

We are investigating the technical feasibility of injecting CO_2 for carbon sequestration with enhanced gas recovery (CSEGR) in the depleted Altmark natural gas reservoir, Germany. Our approach is numerical simulation using TOUGH2/EOS7C. Our earlier simulation studies have shown early CO_2 breakthrough due to fast-flow through the high-permeability sand layers. In order to extend the period of enhanced CH_4 recovery, we propose the pre-injection of gelling fluids for the purpose of limiting the mobility of injected CO_2 and thereby improving CO_2 sweep and delaying CO_2 breakthrough. We have implemented a simple gel model into EOS7C and simulated gel injection followed by CSEGR. Preliminary simulations to date show minimal improvements in CSEGR with breakthrough times delayed by only a few months to a year. While mobility control using pre-injected gelling fluids appears to be a promising strategy in controlling early breakthrough, more work is needed to design and simulate an effective procedure.

THE ALTMARK

The natural gas reservoirs of the Altmark region (52.8 N, 11.0 E) are situated in the Federal State Sachsen-Anhalt, in North Germany. The area belongs to the North German Basin, which forms part of the Mid-European Basin. The main subreservoir of the nine Altmark subreservoirs is Salzwedel-Peckensen, which is also the most important gas field in Germany. The Altmark reservoir is a faulted and compartmented anticlinal structure covered by a massive salt cap rock (Figure 1).

The reservoir itself is composed of alternating sandstone, claystone, and siltstone at a depth of approximately 3000 m. The reservoir pressure is approximately 20 MPa, the temperature is about 120 ˚C. Usable storage porosity, defined as the porosity available to store injected CO_2, is estimated to average 8 % (Schumacher and May, 1990). The permeabilities vary from 0.5 mD to 1000 mD, representing hydrostratigraphic units with higher amounts of clay and silt, and higher amounts of sand, respectively. Further information on the reservoir can be found in Rebscher and Oldenburg (2005).

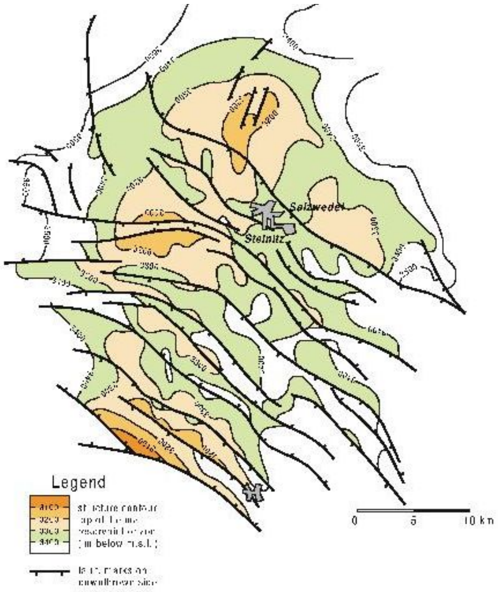


Figure 1. *The map of the Altmark region depicts the structure contours on top of the main reservoir horizon in the Rotliegend and the mainly NW-SE oriented faults (Krull, 2003).*

GAS MIXTURE PROPERTIES

The natural gas in the Altmark is rich in nitrogen, ranging from 40 % to 90 %, with an average methane (CH_4) content of 32 %. In order to avoid the complexities of simulating a four-component gas mixture (CH_4-N_2-CO_2-H_2O), we evaluated the gas properties compressibility-factor, density, and viscosity at Altmark reservoir conditions to compare the CH_4-N_2-CO_2 ternary system with the two-gas system CH_4-CO_2. The comparisons were made using a source-code version of GasEOS (http://lnx.lbl.gov/gaseos). Comparisons show that the gas-mixture can be approximated as a CH_4-CO_2-H_2O system amenable to simulation using EOS7C (Rebscher and Oldenburg, 2005).

THE MODEL

The simplified 3D model includes vertical zoning representing Salzwedel-Peckensen. The model system is discretized as nine layers with six different rock types each with homogeneous, isotropic properties spanning a total thickness of 226 m (Table 1).

The geometry modeled is a quarter of a five-spot pattern with a well spacing of 2.1 km with more than 4000 gridblocks (Figure 2). Usable porosities lie between 5 % and 15 % and permeabilities range from 0.5 mD to 1000 mD depending on the lithology. Details of the model development and properties can be found in Rebscher and Oldenburg (2005).

Calculations are performed using the general-purpose numerical simulation program TOUGH2 (Pruess et al., 1999) and EOS7C (Oldenburg et al., 2004) with a modification to handle a gelling fluid after Finsterle et al. (1994).

Table 1. The gas-bearing layers in the Altmark.

Sequence	Litho-logy	Thickness [m]	Usable Porosity [%]
Zyklus 17	silt	42	8
Zyklus 16	silt	30	5
Zyklus 15	silt	28	5
Zyklus 14	sand	17	14
Zyklus 13	sand	12	15
Zyklus 12	clay	25	5
Zyklus 9-11	silt	43.5	8
Zyklus 8	sand	22	15
Zyklus 7	sand	16	5

3D-SIMULATIONS

Starting from steady-state conditions, constant temperatures of 120 °C, and a hydrostatic pressure distribution above 20 MPa assigned to the lowest layer, a 40 year active period of CH_4 extraction and simultaneous CO_2 injection is simulated. Sink and source sites representing wells are realized through vertical columns continuing from top to bottom, at opposite corners of the model cube (Figure 2). Various scenarious were investigated to simulate representive cases, e.g., variation of permeability of the rock layers and total CO_2 injection rate.

Due to the injection of CO_2 the reservoir repressurizes. The gas injection sweeps the CH_4 towards the extraction well. Figure 3 shows the development of the CO_2 concentration in the gas phase in a diagonal slice of the 3D grid. The time of breakthrough at the production well is essentially determined by the permeability of the high-permeability layers. Here permeabilities of 10^{-11} m^2 lead to breakthroughs after about 2.5 years, while permeabilities of 10^{-13} m^2 results in breakthrough just under 10 years (Figure 4). The various cases (a1-a11) are fully described in Rebscher and Oldenburg (2005). These results from this base-case simulation showing early breakthrough and incomplete CO_2 sweep motivate the search for approaches to improve the effectiveness of CSEGR.

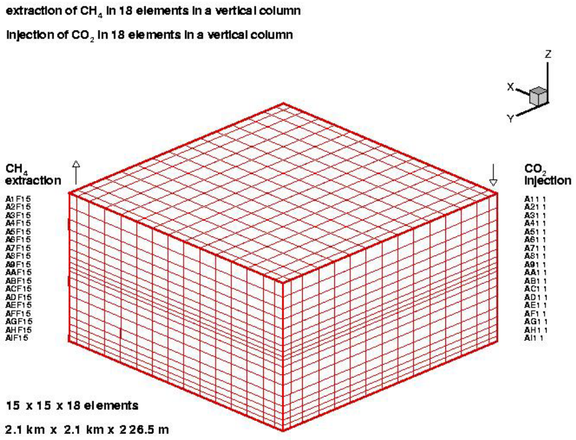


Figure 2. The 3D mesh is discretized in xyz into 15 x 15 x 18 gridblocks. The lateral dimensions of the gridblocks at the edges are adjusted appropriate to the five-spot symmetry of the system. Injection and extraction sites are located in opposite corners.

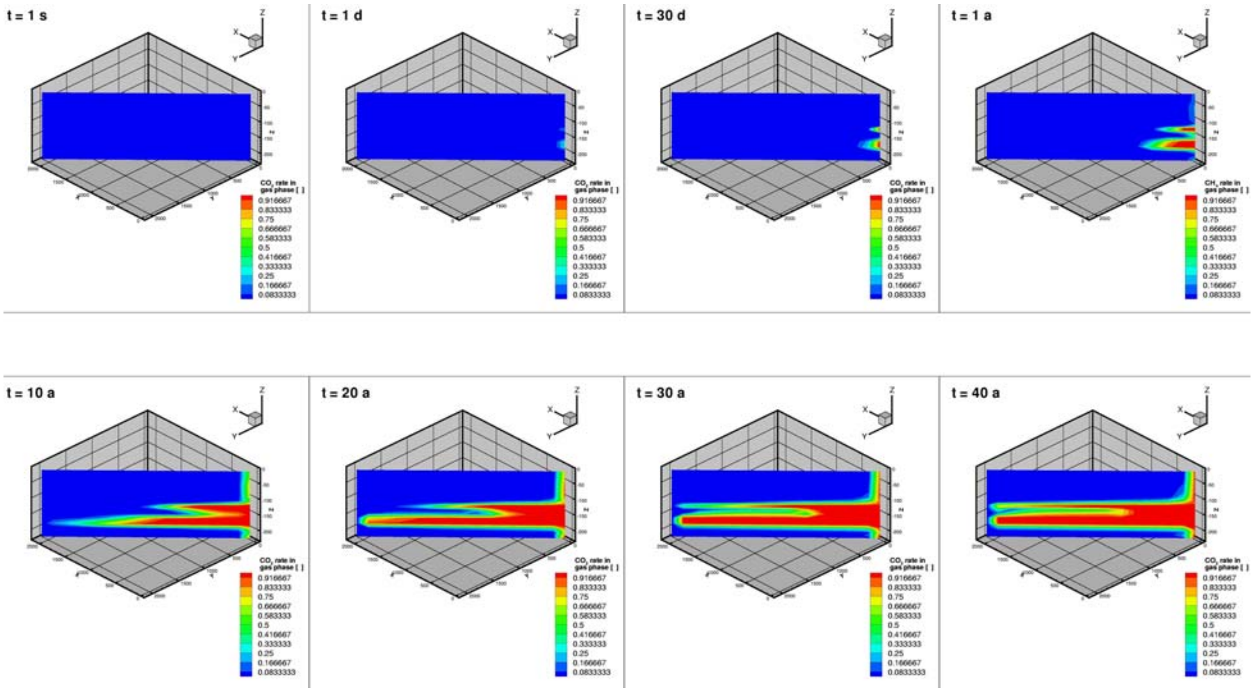


Figure 3. The distribution of the CO_2 mass fraction in the gas phase during the CH_4 extraction and CO_2 injection phase (total CO_2 injection rate Q is 8 kg/s) shows the filling with CO_2 mainly in the two high permeable layers Zyklus 13 and Zyklus 9-11 during the active period of 40 years.

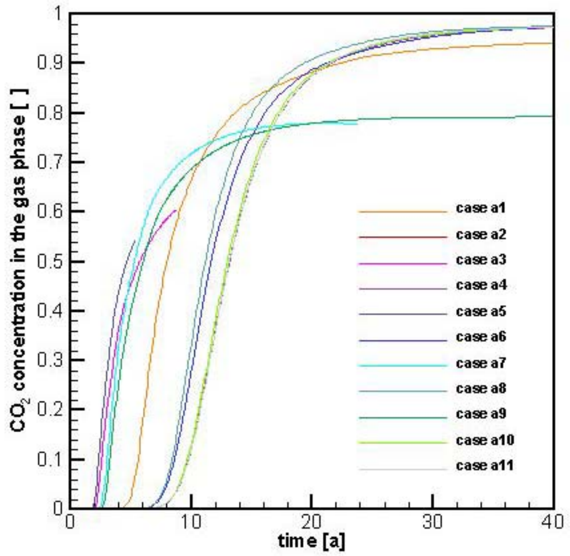


Figure 4. *Evolution of the CO_2 mass fraction in the gas phase close to the production well for 11 cases with varying layer permeabilities as low as 5 x 10^{-17} m^2 to 2.5 x 10^{-15} m^2 and as a high as 10^{-13} m^2 to 10^{-11} m^2.*

BLOCKING WITH WATER

The ultimate economic success of EGR at a depleting gas field depends mainly on the amount of CO_2 contamination in the produced gas, the time over which uncontaminated CH_4 can be produced, and how much additional natural gas can be produced on a given time scale. In order to study extending the EGR period, we simulated different mobility-reducing strategies. One approach is the pre-injection of water into high-permeability layers to control CO_2 mobility (Figure 5).

Different amounts of H_2O were injected for 5 or 10 years in the one or two high permeable layers while simultaneously extracting CH_4 Once the water is emplaced, CO_2 injection (total injection rate Q between 2.9 kg/s 14.5 kg/s) with simultaneous CH_4 extraction is performed as described above. Compared to the simulations without water blocking, the breakthrough is delayed for only an additional year or so.

In general, the following processes reduce the effectiveness of H_2O injection for mobility reduction: First, the injected CO_2 displaces the water. In the two-phase gas-water system, the available pore space for the gas is reduced resulting in an unwanted higher gas-flow velocity. In addition, flow of H_2O due to gravity is significant. Thus the fast path through the high-permeability unit is reopened as water slumps downward due to gravity. The conclusion is that the breakthrough times are increased when water is pre-injected, but the increase is very modest. These results suggest the need for a more sophisticated solution to the problem of early breakthrough.

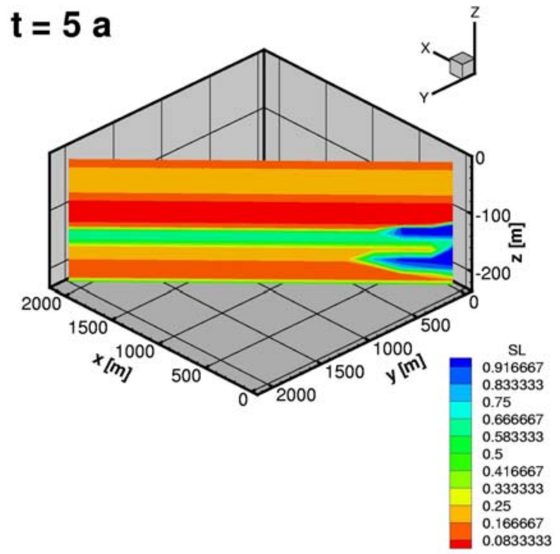


Figure 5. Liquid saturation in the 3D model slice after water injection for 5 years in the two high-permeability layers Zyklus 13 and Zyklus 9-11.

BLOCKING WITH GEL

For blocking with gel, a modified EOS7C module was used which increases the viscosity of water by a certain amount with time, mimicking the behavior of polymer gels. The injected fluid becomes less and less mobile as it gels due to the viscosity function describing the changing viscosity μ_{gel}:

$$\mu_{gel} = \mu + \frac{(\mu_{\max} - \mu)}{t_{gel}^{c}} t^{c} \tag{1}$$

Here μ is the viscosity of water, c is a constant, t is the time, and t_{gel} is the time after which the maximum viscosity μ_{max} is reached. After the gel injection, the 40-year-long CO_2 injection with simultaneous CH_4 production is carried out.

Simulations were performed varying parameters c, μ_{max}, and gel injection rate in one or two high-permeability layers for up to five years. The simulations so far show that the unwanted breakthrough is only slightly delayed relative to blocking with water. For example, comparing a CO_2 injection case with $Q_{\mathrm{CO2}} = 1.6$ kg/s, the occurrence of 1 % CO_2 close to the production site is delayed by about two months when injecting water for 1 year with $Q_{\mathrm{H2O}} = 2.7$ kg/s, and about four months when injecting for one year a gel with a five times higher viscosity and $Q_{\mathrm{gel}} = 2.7$ kg/s.

Figure 6 shows the distribution of gel after the injection of gel for one year ($Q_{\mathrm{gel}} = 2.7$ kg/s) in the high-permeability layers Zyklus 13 and Zyklus 9-11. The blue area indicates the location of the gel. The four diagrams illustrate the development in time of the gel during the CO_2 injection ($Q = 1.6$ kg/s) with simultaneous CH_4 extraction. Figure 7 shows the distribution of the CO_2 mass fraction in the gas phase for the same case at the same time steps.

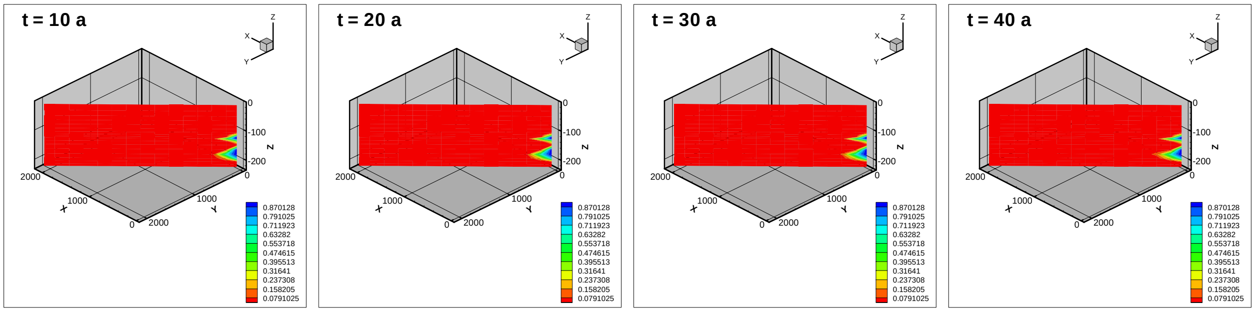
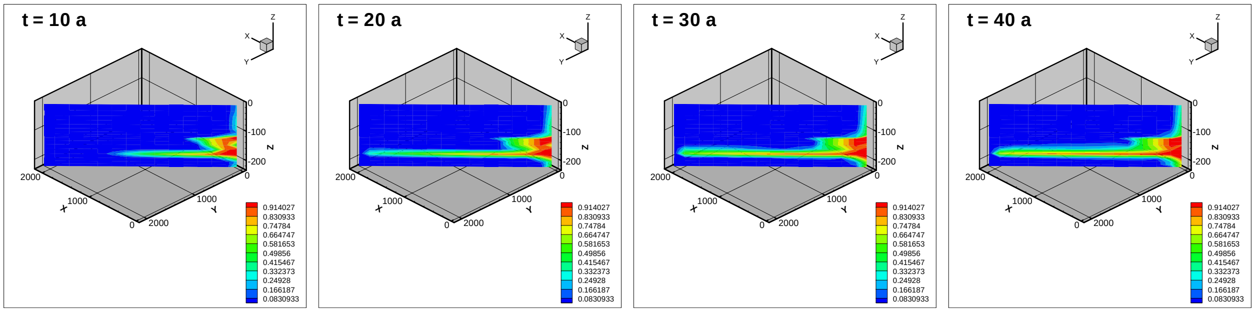


Figure 6. Distribution of gel during 40 years of CH_4 extraction and CO_2 injection ($Q = 1.6$ kg/s), *with previous gel injection* ($Q_{\mathrm{gel}} = 2.7$ kg/s) *for 1 year in the high-permeability layers Zyklus 13 and Zyklus 9-11* ($\mu_{max} = 5\mu_{water}$, $c = 2$).



t = 10 a

t = 20 a

t = 30 a

t = 40 a

Figure 7. Distribution of CO_2 mass fraction in the gas phase during 40 years of the CH_4 extraction and CO_2 injection (same case as in Figure 6).

CONCLUSION

We have developed a simple model of the Altmark gas reservoir and carried out preliminary simulations of CSEGR using TOUGH2/EOS7C. The simulation results presented here are based on non-proprietary published data. As such, the model is generic and should not be used for detailed reservoir prediction. However, the simulations contribute to the understanding of complex processes including phase interference and gas displacement. For the purposes of mobility control and delay of CO_2 breakthrough, gel injection is a logical choice, but more work is needed to design and simulate effective strategies. In general, CSEGR appears to be promising for increasing gas production in the Altmark gas fields while simultaneously sequestering CO_2. More specific predictions can be obtained by further simulations based on detailed field data.

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