PS Compressibility and Brine Permeability of Reservoir and Seal of Pore Space Gas Storages*

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Abstract

Underground gas storages (UGS) play an important role in today's gas supply. Typical UGS sites are salt caverns, aquifers and former natural gas and oil reservoirs. The latter represent pore space gas storages. We studied a potential UGS in the Molasse basin, southern Bavaria (Germany), consisting of a fine-grained reservoir sandstone underneath a marlstone seal. UGS will have particular significance on "power to gas" projects, where wind or solar power is transduced to synthetical CH_4. “Power to gas” usage of UGSs will lead to a higher frequency in depletion and refilling cycles and possibly faster material fatigue as is the case nowadays. Consequently, material fatigue of the UGS rocks is an issue of paramount importance for gas storage operators. We present here results of cyclic compressibility tests which are aimed to find out if and how the poroelastic parameters change with ongoing cyclic deformation. We carried out a sequence of hydrostatic CPV tests (CPV = compressibility of pore volume) alternating with an aging procedure. The modelled aging of the reservoir sandstone and its seal in the range of 18 years (seal) to 21 years (reservoir) was achieved by cyclic pore pressure increase and decrease – simulating the depletion and refilling of the UGS. The important determined poroelastic parameters are the bulk compressibility and the compaction coefficient. Bulk compressibility data for the reservoir sandstone before and after both aging procedures are very much alike. Obviously full elasticity is preserved over the simulated time of storage use. Bulk compressibility of the seal marlstone is about half a magnitude lower than for the reservoir sandstone. Simultaneously, the seal experiences double the volume strain during CPV01 and only 25% of it during CPV02 compared to the reservoir sandstone. Nevertheless, the bulk compressibility is almost unaffected by the change in volume strain and it seems that elasticity prevails also within the seal of the UGS. The compaction coefficient of the seal marlstone is up to two magnitudes higher than the compaction coefficient of the reservoir sandstone. This behavior may be the result of the swellability of the marlstone. Coevally, the compaction coefficients do not change a lot for both lithologies: this is another hint for ubiquity of elasticity over the entire testing process. Compressibility tests as those presented here are an invaluable tool for the determination of the poroelasticity of a UGS. Although different in compressibility and compaction, the sandstone and the marlstone have one thing in common: a high reproducibility of the data which points to the prevalence of elasticity during the entire deformation and aging process. Nevertheless, further tests are necessary to verify our so far observations before they may be applied to the entire investigated reservoir-seal system or even transferred to other UGSs.

Compressibility and brine permeability of reservoir and seal of pore space gas storages

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1. Introduction: The principle of a pore space underground gas storage (UGS)

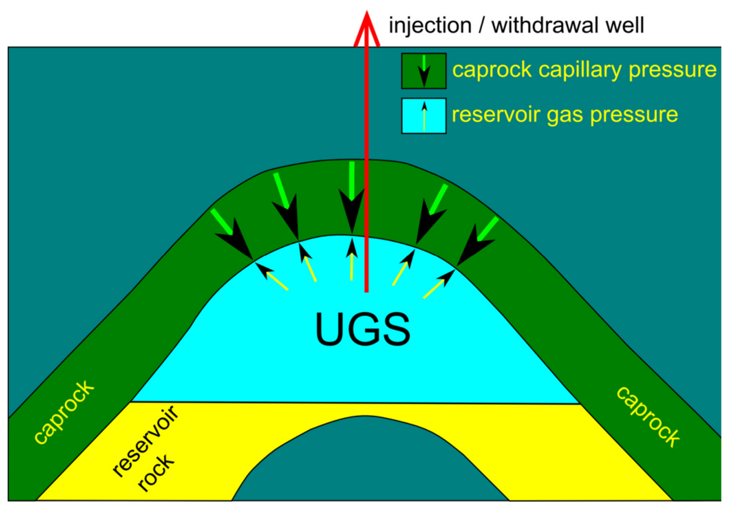

Fig. 1: Schematic sketch of a pore space underground gas storage (UGS).

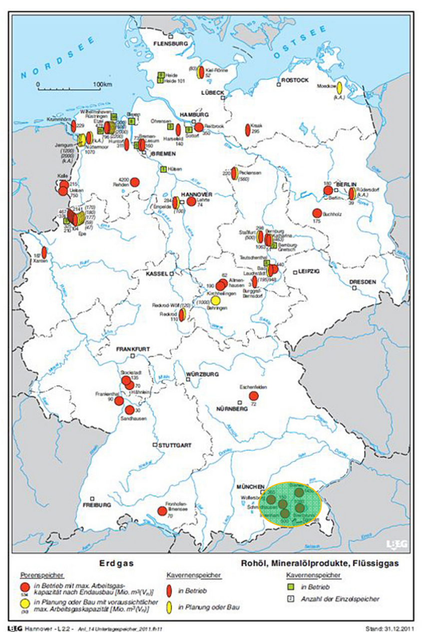

Fig. 2: Location of the investigated UGS within the framework of hydrocarbon storages (within the green elipse).

Underground gas storages (UGS) play an important role in today's gas supply. Typical UGS sites are salt caverns, aquifers and former natural gas and oil reservoirs. The latter represent pore space gas storages (Fig. 1). We studied a potential UGS in southern Bavaria (Fig. 2), consisting of a fine-grained reservoir sandstone underneath a marlstone seal.
UGS will have particular significance on "power to gas" projects, where wind or solar power is transferred to hydrogen and oxygen which can be used e.g. for methanation, i.e. the formation of artificial CH_4 from the above mentioned hydrogen and carbon from decarbonisation processes.

In contrast to today's gas storage, which is controlled by the seasonal heating cycle and characterized by storage filling in summer and storage depletion during winter, methanation CH_4 gas storage will be characterized by much shorter depletion and refilling cycles.
Already nowadays material fatigue of the UGS rocks is an issue for gas storage operators. However, it will be a topic of paramountcy as soon as "power to gas" storage is concerned.
We present here results of cyclic compressibility tests and brine permeability measurements which are aimed to find out if and how key rock physical parameters change with ongoing cyclic deformation.

2. Equipment and testing technology

The compressibility tests were carried out on a digitally controlled servo hydraulic testing machine with a maximum load of 600 kN. The specimens were mounted in a triaxial cell with exchangeable pistons (Fig. 3). The pistons are perforated to provide drained conditions. True axial and radial deformation of the specimen are measured "in-vessel" to avoid the load frame deformation being included in the results.

To avoid friction artefacts, the axial load is measured with an in-vessel load cell. The sample is situated within a semi-rigid core sleeve. The pore pressure is generated with a syringe high precision Quizix metering pump system.

The Quizix pump system plays also an important role in the brine permeability / threshold pressure device of Gesteinslabor (Figs. 4-6). Brine permeability determination is done at in situ conditions - the steady state permeability can be determined by applying a differential pressure onto the specimen. The system has to equilibrate until a stationary pressure gradient within the specimen is reached. As soon as equilibration is reached, the injection rate equals the output flow rate and all parameters are constant over time. From fluid flow the permeability can be calculated by applying Darcy's law for flow in porous media.

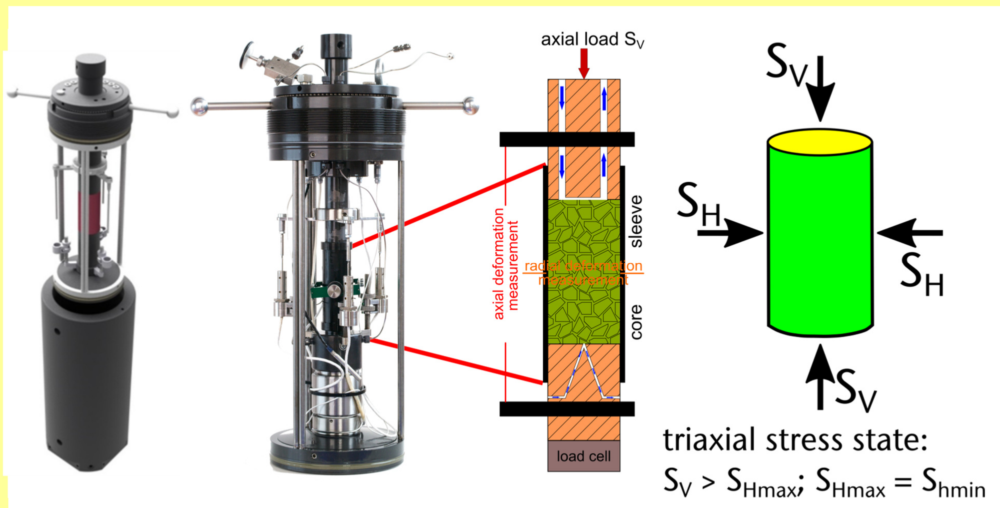

Fig. 3: In-vessel testing setup with three LVDTs and the radial strain gauge. The exchangeable pistons are perforated to allow testing under drained conditions. Complete pressure vessel to the left and stress configuration around the specimen to the right.

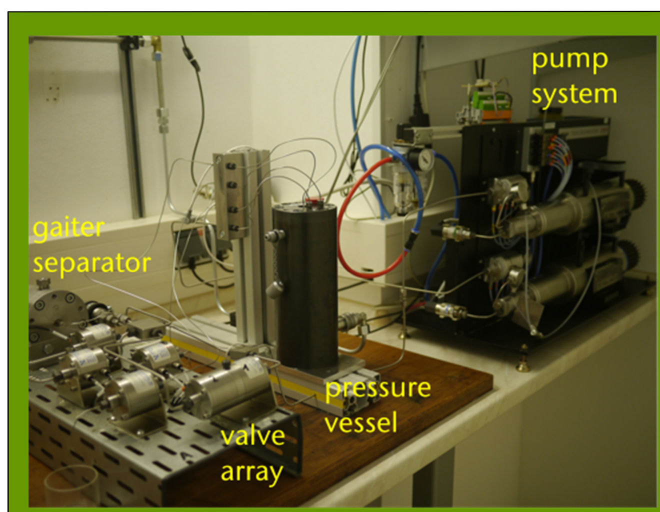

Fig. 4: Photograph of the threshold pressure / brine permeability device at Gesteinslabor: Visible is one pressure vessel, part of the tubing-valve-fluid-system plus the high precision syringe pump.

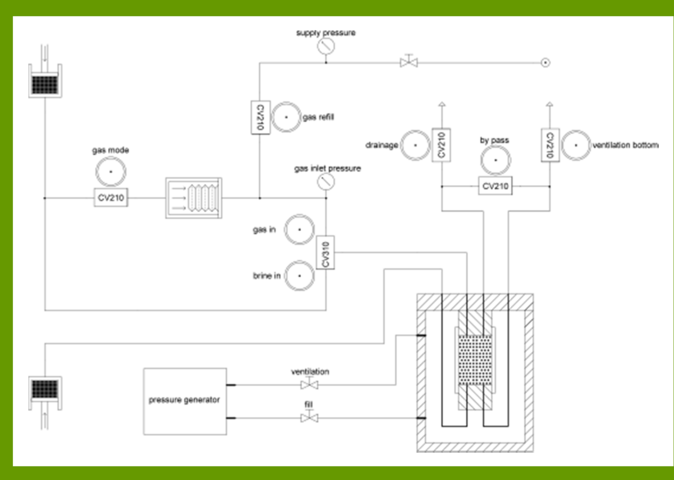

Fig. 5:The experimental setup of the brine permeability / threshold pressure device at Gesteinslabor as circuit diagram.

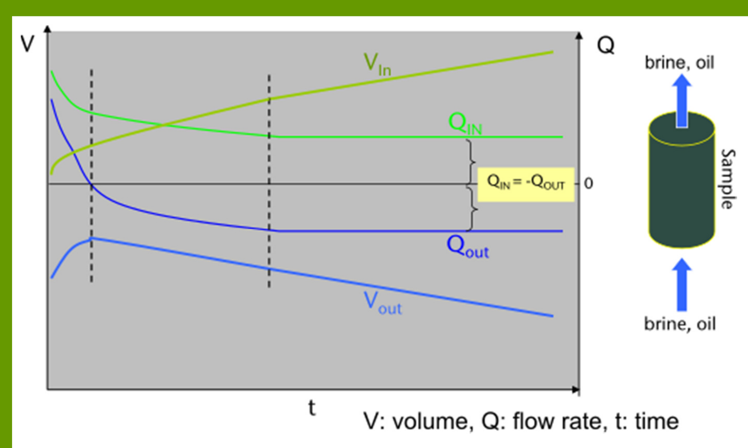

Fig. 6: Idealized run of a brine permeability measurement at Gesteinslabor. Derived data are steady state permeability data.

3. Testing procedure and results

Brine permeability

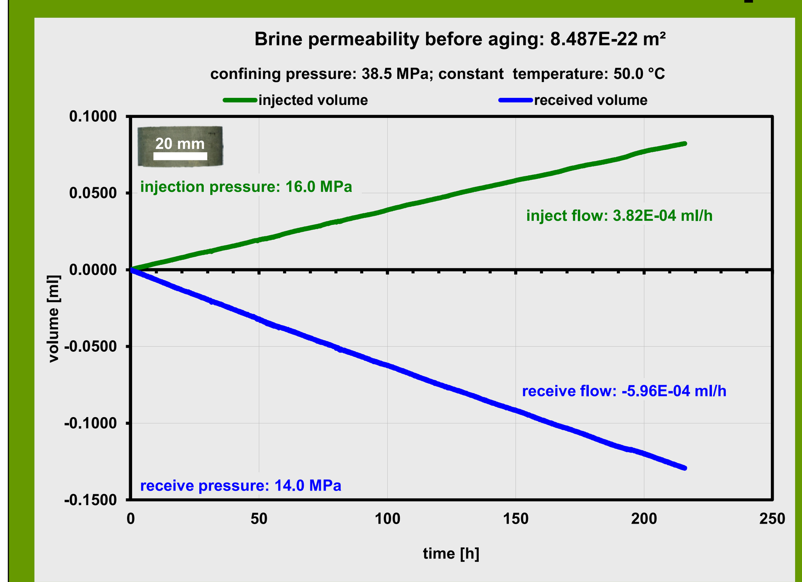

Fig. 7: Before the aging procedure the caprock has a very low brine permeability of < 10^{-21} m². The inlay in the top left corner shows the brine permeability plug.

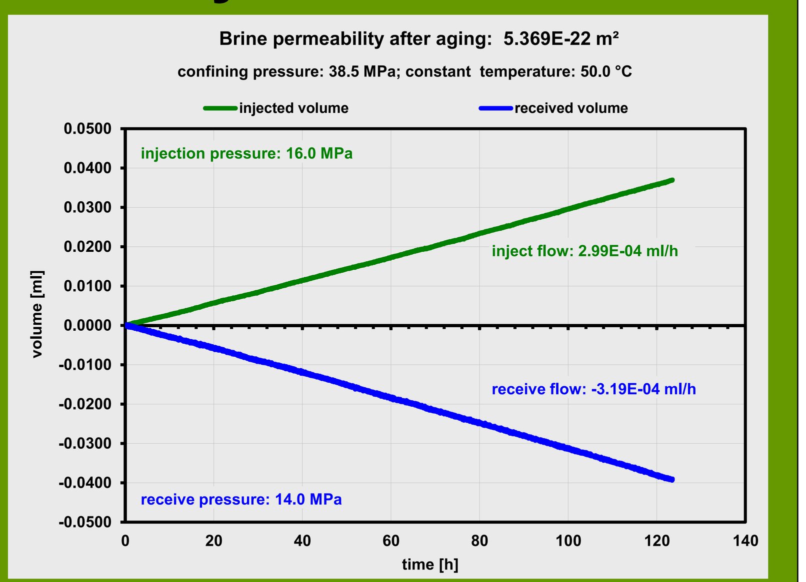

Fig. 8: After 20 simulated years of aging the brine permeability has decreased by roughly one third of a magnitude.

Brine permeability K_b was determined at in situ conditions, i.e. at 50°C and a confining pressure P_c of 38.5 MPa; the fluid injection pressure was set to the pore fluid pressure P_p within the reservoir of 16 MPa. K_b was measured twice: before and after an aging procedure, which is characterized by cyclic releases of P_c from 38.5 MPa to ambient conditions and subsequent reloading to the in situ P_c. By this measure 20 years of storage use were simulated.
The pre-aging brine permeability measurement resulted in a K_b value of 8.5*10^{-22} m² (Fig. 7). After 20 aging cycles Kb decreased to 5.4*10^{-22} m² (Fig. 8). It seems that the unloading/loading cycles led to compaction of the seal marlstone expressed by a decrease in permeability.
Compressibility tests were carried out in a cyclic manner. We started with hydrostatic CPV tests (Fig. 9; (CPV = compressibility of pore volume) for the determination of the bulk compressibility followed by an aging procedure (Fig. 10) and a second CPV test. Aging of the reservoir sandstone and its seal in the range of 20 years was achieved by cyclic P_p /P_c increase and decrease – simulating the depletion and refilling of the UGS similar to the aging cycles done for the brine permeability determination..
The bulk compressibility curves for the reservoir sandstone (Fig. 11) before and after the aging procedure are very much alike and show that full elasticity is preserved over the simulated aging period. Bulk compressibility of the seal marlstone is about half a magnitude lower than for the reservoir sandstone (Fig. 11). Simultaneously, the caprock experiences double the volume strain during CPV01 and only 25% of it during CPV02 compared to the reservoir sandstone. Nevertheless, the bulk compressibility is almost unaffected by the change in volume strain and it seems that elasticity prevails also within the seal of the UGS.
The aging procedure allows the determination of the modified compaction coefficient by plotting volume strain as a function of pore pressure (Fig. 12). The compaction coefficient of the caprock is up to two magnitudes higher than the compaction coefficient of the reservoir sandstone, i.e. volume strain changes much faster with changing pore pressure as is the case for the reservoir sandstone. This behavior reflects the strong mechanical discrepancy of both the lithologies, probably in particular the swellability of the marlstone. Simultaneously, the compaction coefficients do not change a lot for both lithologies: this is another hint for prevalence of elasticity over the entire testing process and the lack of material fatigue.

Compressibility

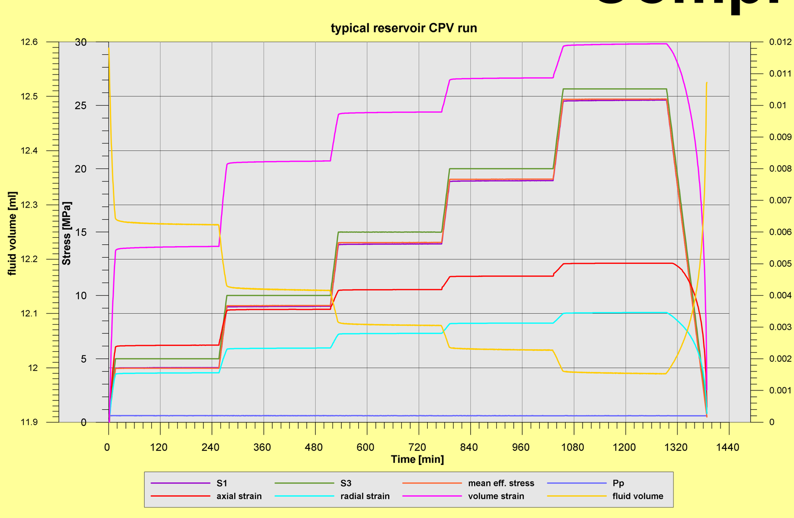

Fig. 9: Typical metering cycle for a reservoir CPV test.

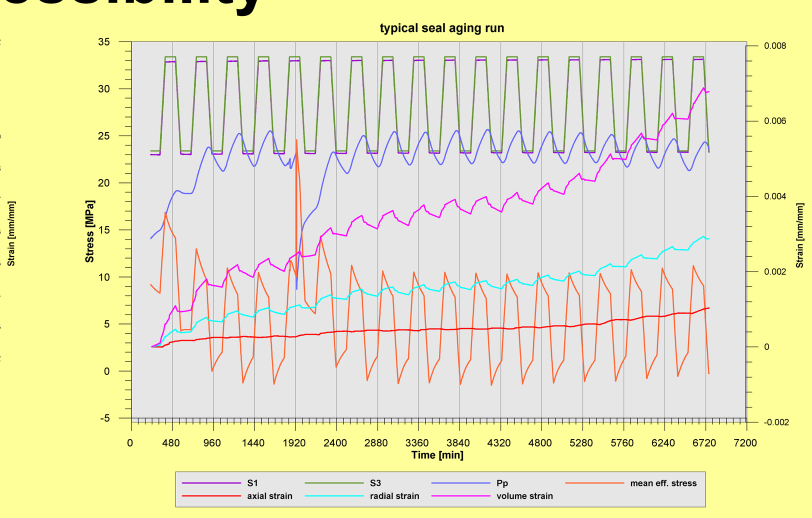

Fig. 10: Typical metering cycle for the seal aging procedure.

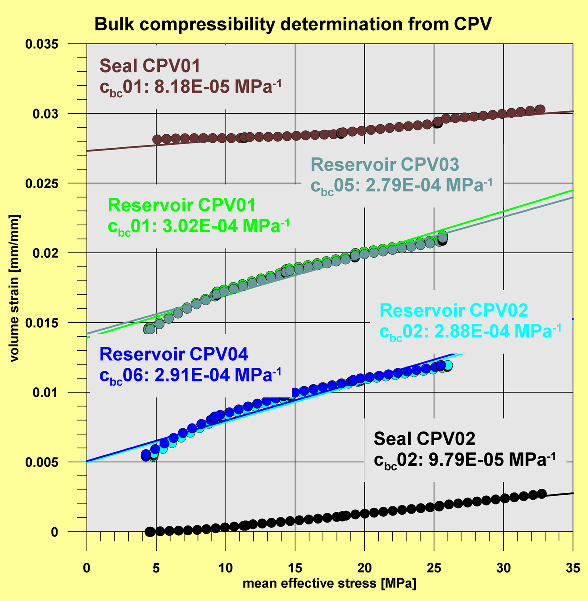

Fig. 11: Bulk compressibility data for the reservoir sandstone and the seal marlstone as determined by the CPV tests.

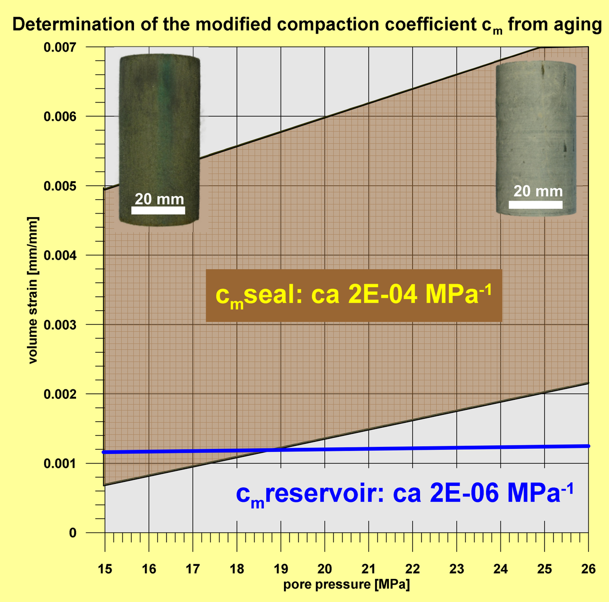

Fig. 12: Compaction coefficient data for the reservoir sandstone and the seal marlstone as determined by the aging procedure. Inlays: top left: typical reservoir sandstone plug, top right: typical seal marlstone specimen.

4. Conclusions

Compressibility tests and brine permeability measurements as those presented here are an invaluable tool for the determination of the rock physical behavior of UGS reservoir rocks and their seals.
In the present case we were able to determine the bulk compressibility of a fine grained reservoir sandstone and its seal – a marlstone – from CPV tests. An aging procedure placed between the individual CPV tests not only simulated roughly 20 years of UGS use, but also yielded compac-tion coefficients for both lithologies. Although different in compressibility and compaction behavi-or, the sandstone and the marlstone show a high reproducibility of the data which points to the prevalence of elastic behavior during the entire deformation and aging process.
Brine permeability decreases slightly due to aging and probably in response to compaction of the seal marlstone.
All our results point to the fact that cyclic storage use in the current case does not lead to material fatigue.

IfG · Gesteinslabor Dr. Eberhard Jahns · HoMe Hochschule Merseburg · Martin-Luther-Universität Halle-Wittenberg · Technische Universität Darmstadt · GFZ Helmholtz Centre Potsdam · KIT Karlsruher Institut für Technologie · DGMK