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15-year experience of acid gas storage in the natural gas structure of Borzęcin – Poland

The natural gas produced by Polish Oil & Gas Company from the Borzecin reservoir contains 0.3% of CO_2 and 0.05% of H_2S and, consequently, undergoes the sweetening process with amine installation. The acid gas generated as a byproduct of the amine process is reinjected into an underlying water zone in hydrodynamic contact with the gas bearing reservoir [1].

The reinjected acid gas consists of about 60% of CO_2 and 15% of H_2S. Upon the reinjection it partially dissolves in the underlying water and further migrates upwards into the gas cap and, consequently, may influence the composition of produced gas.

These reinjection facilities have been in operation on the Borzecin gas installation since the end of 1995 when 67% of the original gas in place had already been recovered. According to the best knowledge of the authors the Borzęcin case is the first site in the world where acid gas reinjection is performed into the original gas deposit, contrary to what is claimed in the paper [7], where a similar installation is described to have started operation in 2004.

The diagram showing acid gas reinjection into the Borzecin structure is presented in Figure 1.

Designing process of the Borzęcin reinjection facilities was preceded by laboratory experiments carried out in the

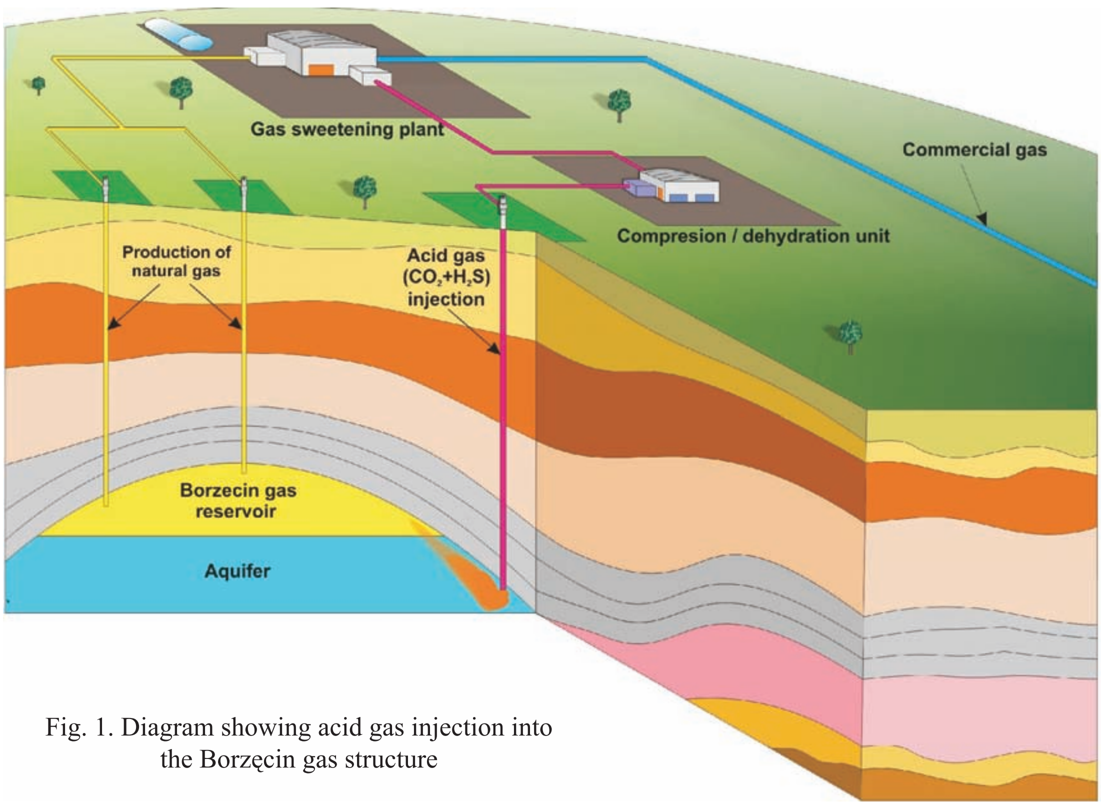

Fig. 1. Diagram showing acid gas injection into the Borzęcin gas structure

Polish Oil & Gas Institute. They revealed large contrast between original gas (with 65% of hydrocarbons) solubility in water and that of the reinjected acid gas under the reservoir conditions. The former proved to be 8 times smaller than the latter one [4]. These PVT test results show that the volume of methane displaced from reservoir water is directly proportional to the volume of CO_2 injected into the water. This displacement process causes the effect of the gas cap to be effectively replenished. The modeling simulations of the process, as shown below, indicated the upward movement of the reinjected acid gas to the gas cap to be relatively slow. Phase diagram constructed using computer PVT simulations indicated that injected gas remains in gaseous phase for all temperatures and pressures involved. While monitoring the injection process, a drop of the injection pressure was recorded from 10.4 down to 6.6 MPa after the injection of ca. 18 000 SCm^3.

This effect was probably caused by the increase of the rock permeability due to chemical reactions between the reservoir rock and injected acid gas in aqueous environment [3]. High partial pressure of H_2S and CO_2 components, elevated temperature and pressure are the factors determining the risk of the acid gas leakage during its transport and injection. The continuous monitoring of the steel pipe and tubing well thickness is carried out using Sondex Multi Finger Memory equipment. Its positive results suggest that condensed vapours of MEA, which are present in the injected gas, inhibit corrosion processes.

The 1 km long transmission line from the compressor station to the well site is cased and vented to the flare while the pressure of the annulus space is continuously monitored. In the worst scenario such as blowout of the injection well, the acid gas should be automatically ignited. The tubing-casing annulus of the injector is filled with a corrosion inhibitor.

A reservoir simulation model of the Borzęcin deposit was constructed to be used in the compositional simulation of the reservoir performance under the acid gas reinjection program [6].

The model was constructed based on the following standard information:

- geology: structural trap – anticline within Fore Sudetic Monocline, reservoir rock: Zechstein Basal Limestone (30 m thick), reservoir boundaries: anhydrite caprock, underlying water,

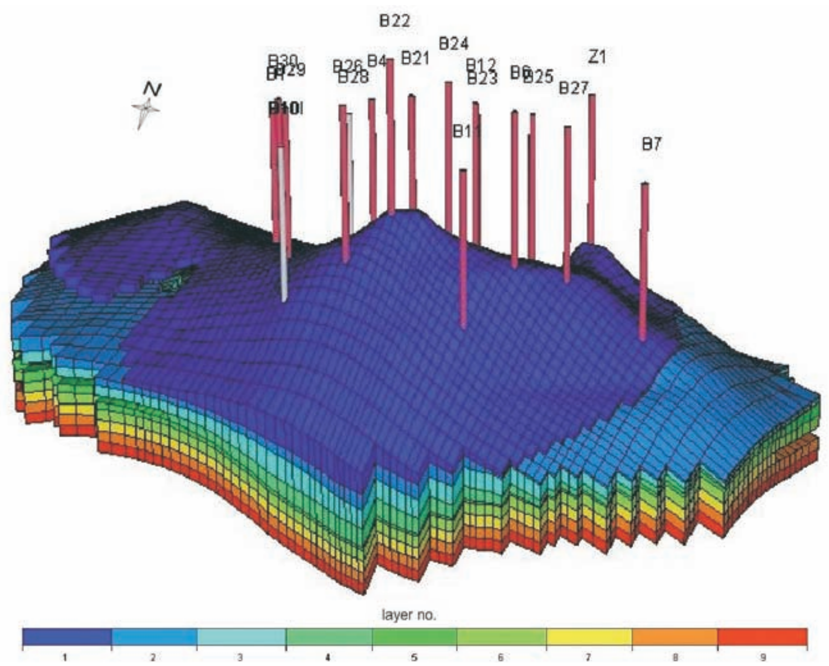

Fig. 2. Perspective view of the Borzecin deposit model

- source data consist of: structural maps, core analysis, well logs, gas and water analysis, other data from neighbor reservoirs of same formation.

  The model is characterized by the following parameters:
- it covers the area of: 10.3 × 6.2 km,
- includes 9 layers (4 limestone + 5 sandstone),
- the grid consists of 69 × 43 × 9 blocks,
- the fluid transport in the structure is of single-porosity, single-permeability type (no fractures),
- the fluid (gas) model consists of 8 components: C_1, C_2, C_{3+} (pseudo-component) and CO_2, H_2S, N_2, H_2, He,
- the equation of state used in the simulation is the Peng-Robinson equation,
- in addition, a solubility of CO_2 and H_2S in brine is taken into account,
- basic parameters of the model are: total pore volume: 338 mln Rm^3, hydrocarbon pore volume 33.3 mln Rm^3, gas originally in place (GOIP) is 4.7 billion SCm^3,

The model was calibrated using production data since 1972 comprising: gas production of individual wells (18 wells), water reinjection (well B-10), bottom hole pressures of all producers, water-gas ratio where recorded and injection data since 1996 include: acid gas injection (well B-28) with injected gas composition (50% CO_2, 16% H_2S+) and compositions of gas produced by individual wells.

Examples of bottom hole pressure match and quality of produced CO_2 concentration match are presented in Figure 3 and Figure 4.

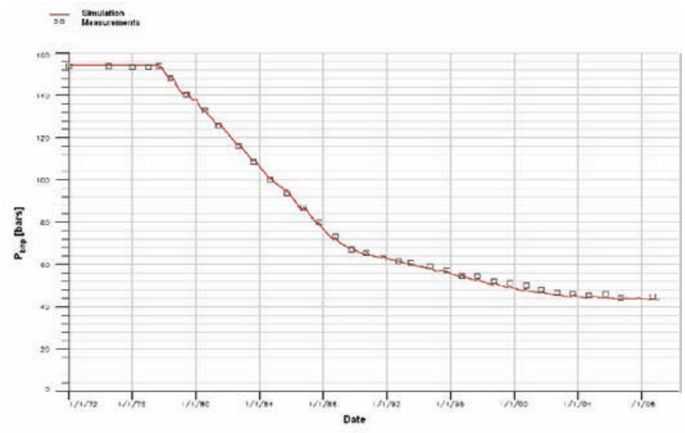

Fig. 3. Example of bottom hole pressure fit for well B-4

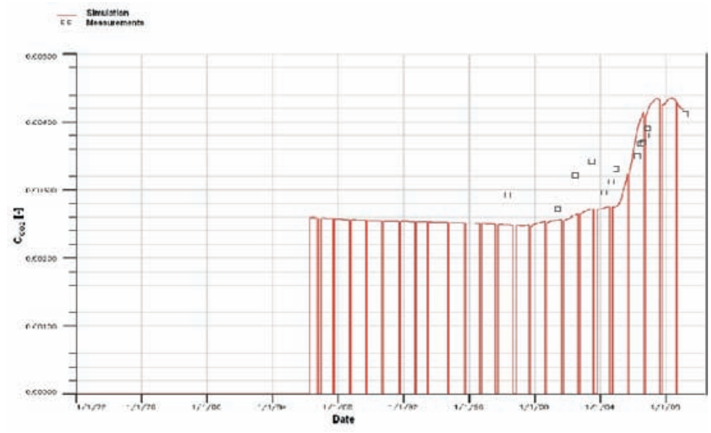

Fig. 4. Example of CO_2 concentration fit for well B-22

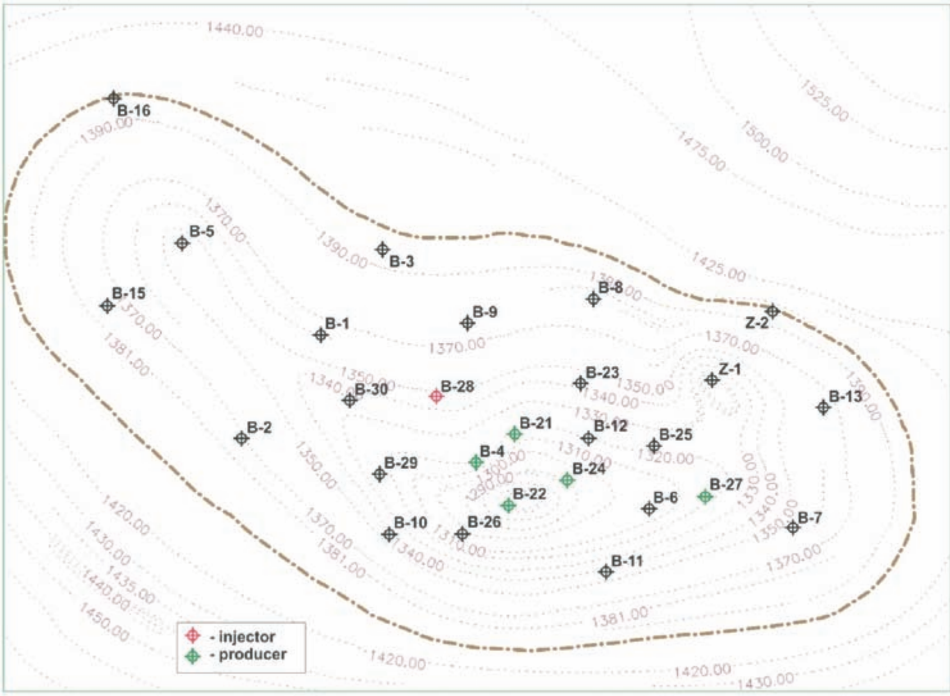

Fig. 5. Map of the Borzęcin structure top with well locations

Figure 5 shows the location of the acid gas injector (B-28) together which recent and current producers (B-4 and B-21, 22, 24, 27).

The dominating force that drives the injected gas migration is the buoyancy effect as the acid gas is injected into the underlying water.

Figure 6 shows a typical behavior of the gas injected into the water beneath the gas cap as results from a detailed segment model corresponding to the Borzęcin structure properties. The injected gas moves directly upwards to reach the gas cap. Then it migrates ac-

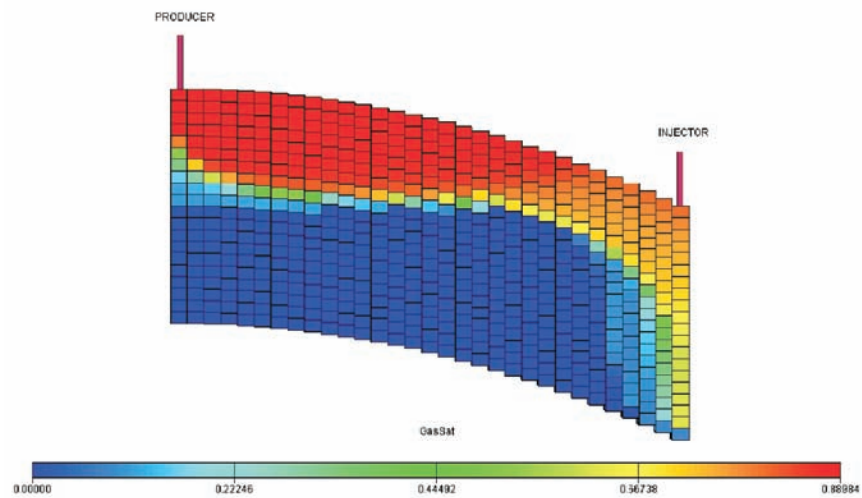

Fig. 6. Gas saturation between injector and producer

cording to the pressure gradients within the cap towards producers.

Figure 7 shows the fluid distribution (original gas and water) in the Borzęcin structure part of interest together with the location of the injector and three closest producers.

Figure 8 shows the migration of CO_2 injected by B-28 and steadily moving towards B-4 and the other wells following the pattern mentioned before.

The amount of CO_2 dissolved in the brine is very limited as shown in Figure 9.

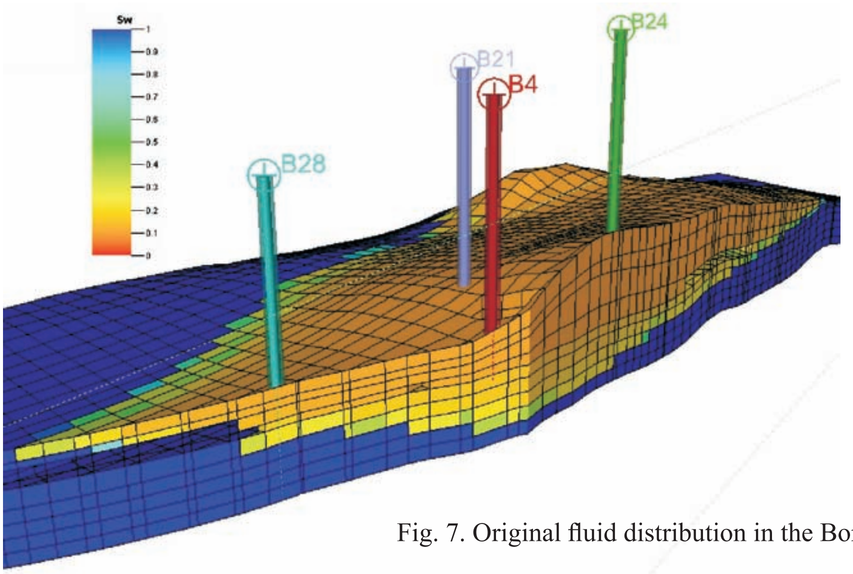

Fig. 7. Original fluid distribution in the Borzęcin structure

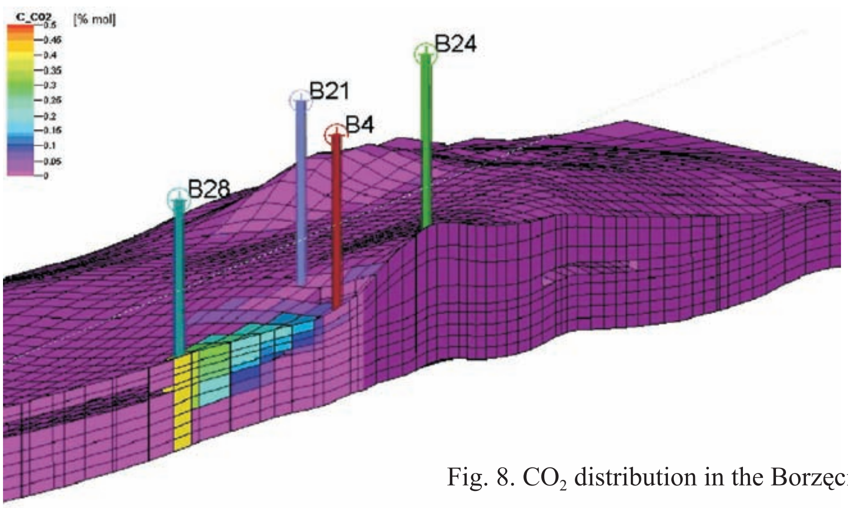

Fig. 8. CO_2 distribution in the Borzęcin structure

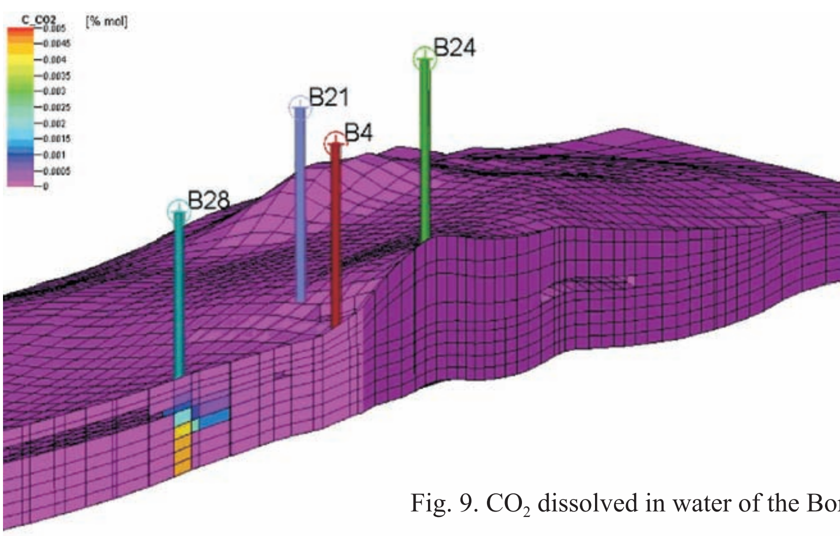

Fig. 9. CO_2 dissolved in water of the Borzęcin structure

To make predictions of the reservoir performance in the future, the rate decline analysis was made as shown in Figure 10 where the exponential decline curve was successfully fitted to the data and used to extrapolate future production.

As the contribution of individual wells in production was almost constant in time, the wells production rates were determined in the prediction phase. These predictions show the following course of events: wells B-24 and B-27 work till the end of the prediction limit (2029), well B-21 is terminated in 2022 by water-gas-ratio increasing above the assumed limit; well B-22 stops in 2026 due to an economic limit.

Figure 11 presents the CO_2 concentration in gas produced by all 4 producers. The time profile of CO_2 concentration is rather complicated due to the significant role of active water. Its encroachment causes certain migration paths for injected gas to be closed which results in non-uniform CO_2 flow to producers. This effect plus the decreasing injection and production rates limits the maximum CO_2 concentration in produced gas to less than 0.5%.

Figure 12 presents changes of CO_2 concentration in the vicinity of the injector and current producers in the left panel. To include the simultaneous water migration the right panel shows changes in water saturation.

Figure 13 shows the concentration of CO_2 dissolved in water at the end of the simulation period. This concentration is still very low and spatially limited to the vicinity of the injector.

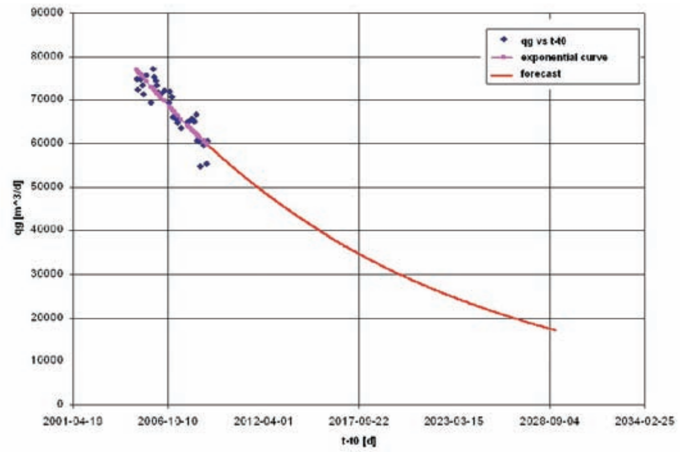

Fig. 10. Gas production decline – curve match and prediction

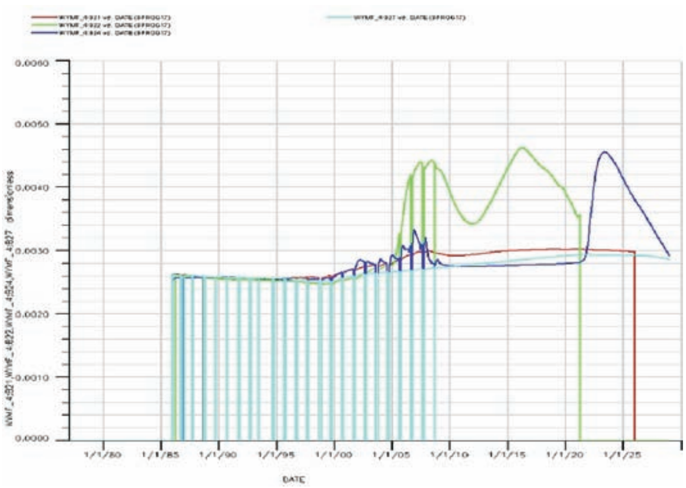

Fig. 11. Simulation prediction of CO_2 concentration in produced gas

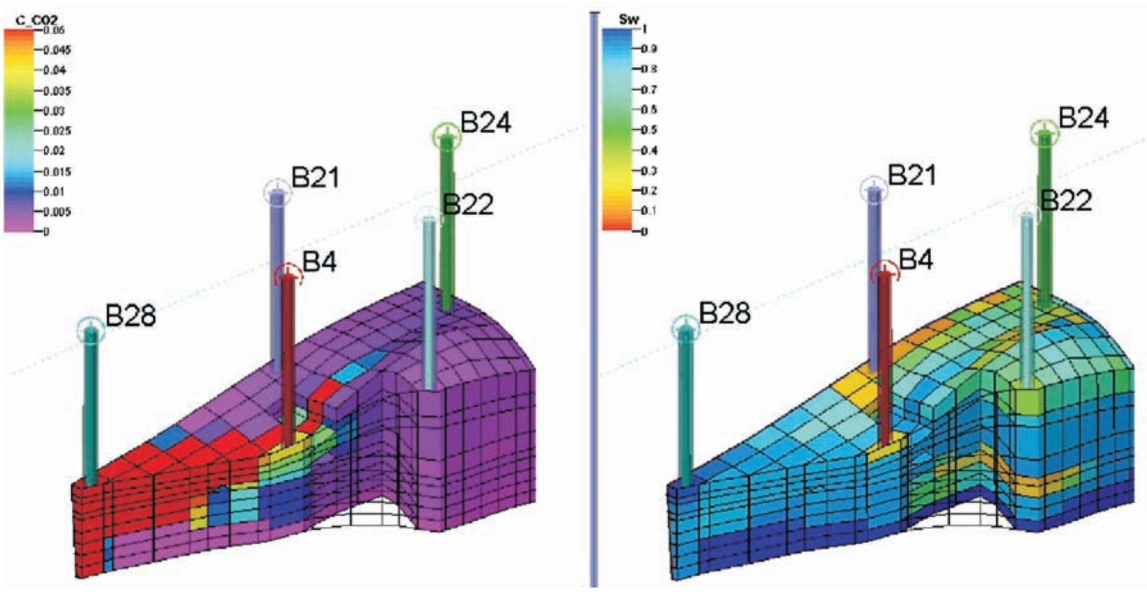

Fig. 12. CO_2 (left panel) and water (right panel) distribution in the Borzęcin structure

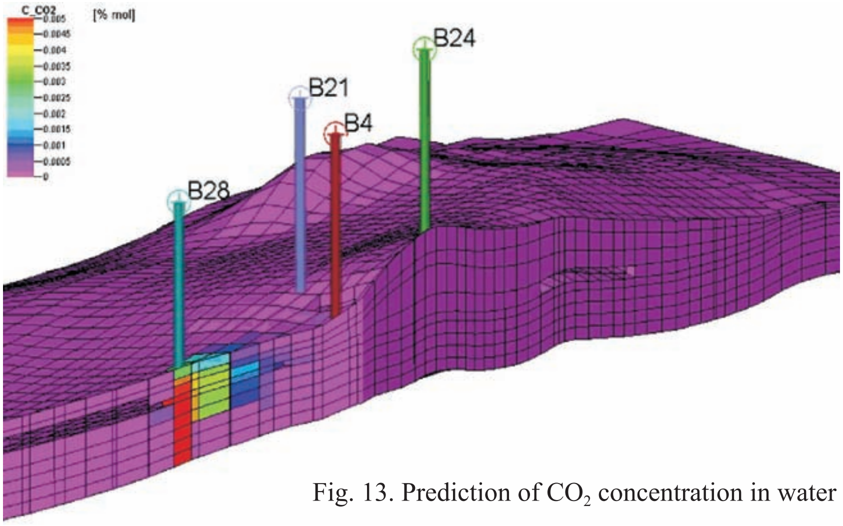

Fig. 13. Prediction of CO_2 concentration in water of the Borzęcin structure

Summary and conclusion

15-year experience of acid gas injection into the Borzecin structure confirmed practical feasibility of acid gas storage in continuously operated gas reservoir.

Constant monitoring of the acid gas storage confirmed safety of the process with respect to chosen materials and technology.

Despite the effective migration of the injected gas to the original gas bearing zone, very low contamination of the original gas production is observed.

Dominating process of the gas storage in water bearing zone is upward migration driven by the buoyancy effect.

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