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Projects of Enhanced Gas and Oil Recovery Using CO_2 Sequestration Processes in Poland

Introduction

For the last several years EC have strongly stimulated various activities to reduce CO_2 emission by carbon capture and storage (CCS) to achieve the predicted reduction by 2020. This policy recommends CO_2 sequestration in geological formations as the priority technology for reducing CO_2 emission from burning fossil fuels. This technology, treated as a temporary solution to the problem, will contribute to the mitigation of climate change and should not enhance the fossil fuel energy sector. In particular, it should not reduce the development of energy saving activities and contribution of renewable and low-emission energy sources in both research and financial aspects. The technology should be an obligatory choice for all new coal-based power plants to be constructed in EU states after 2020 and should be included in modernization plans of existing power-plants. In Poland, this technology is of special strategic interest as 95% of our energy is generated by coal-fuelled power plants.

EU member states are obliged to identify and provide inventory of the geological formations and structures located within their boundaries, which are capable of geological storage of CO_2 from large industrial emitters.

The Polish Oil and Gas Institute together with Polish Oil and Gas Companies have gained valuable experience in the reinjection of acid gas (with high CO_2 concentration) from gas treatment installations to water-bearing geological structures. An acid gas reinjection project started operating in the Borzęcin gas reservior in 1996 as the first project of this type in Europe. The project was mainly aimed at the environmental protection target and the enhanced gas recovery was a secondary effect [1, 7].

Injection of Acid Gases into the Borzecin Gas-water Zone

Displacement of the native gas which originally saturated the underlying water with acid gases injected below the reservoir may increase the recoverable gas reserves. Such a displacement process enables replenishing the gas cap by volume equivalent to the methane gas dissolved in the underlying waters.

The project reported here present reinjection of acid gases containing 60% of CO_2 and 15% of H_2S into an aquifer directly underlying the Borzęcin gas reservoir, see Fig. 1.

The reinjected gases are by-products of the amine gas sweetening process. In this case the injected gas dissolves in the underlying water which has hydrodynamic contact with the gas horizon and thus may influence the composition of the produced gas.

Before designing the injection facility PVT experiments were carried out. The laboratory experiments indicated that:

- solubility of the native gas which contained 65% of hydrocarbons, 35% of nitrogen and small volumes of H_2S and CO_2 was 1.55 SC m^3 of gas per 1 m^3 of reservoir water at 58°C and 97 bars,
- solubility of the injected acid gas which contained 60% of CO_2, 15% of H_2S, 20% of hydrocarbons and 5% of nitrogen was 13 SC m^3 of gas per 1 m^3 of reservoir water at the same temperature and pressure as specified above; this means that it was 8.4 times greater than the solubility of the native gas,
- phase diagram, constructed using computer simulation of PVT experiments indicated that the injected gas

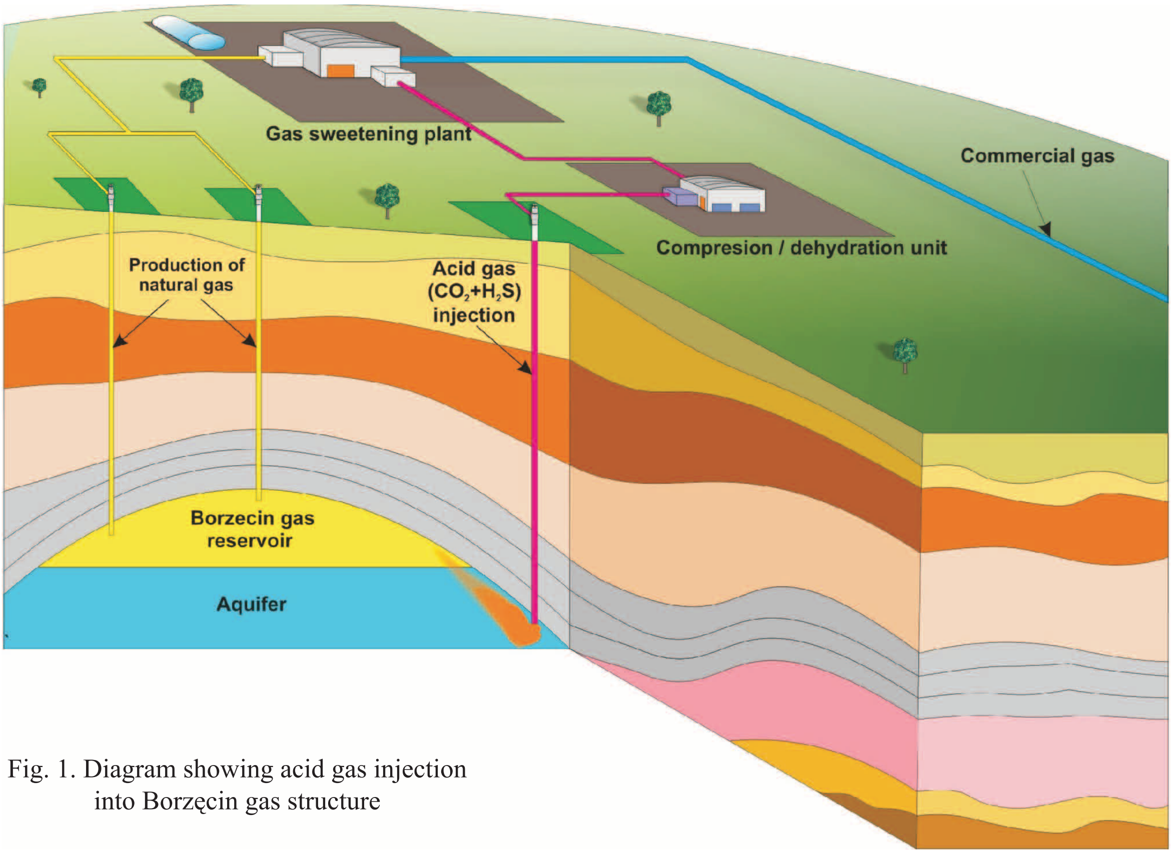

Fig. 1. Diagram showing acid gas injection into Borzęcin gas structure

remained in the gaseous phase at reservoir conditions,

- acid gas dissolves in the reservoir water preferentially displacing the originally dissolved natural gas.

The PVT test results indicated that the volume of methane gas displaced from reservoir water is an increasing function of volume of CO_2 injected into the reservoir. In Fig. 2 we present a prediction of CO_2 concentracion in gas produced by particullar wells.

The 15-year experience of acid gas injection into the Borzęcin structure confirmed practical feasibility of acid gas storage in continuously productive gas reservoirs. Constant monitoring of the acid gas storage confirmed safety of the process with respect to chosen materials and technology. Despite relatively fast migration of the injected gas to the original gas bearing zone – very low contamination of the original gas production is observed.

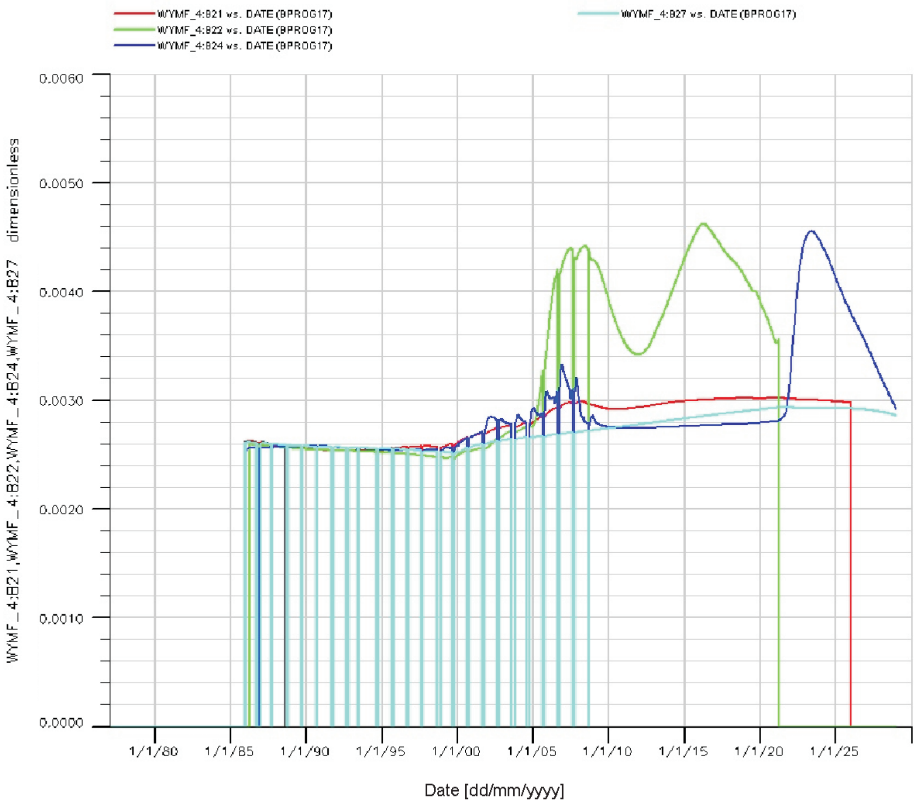

Fig. 2. Borzęcin gas reservoir. Production forecast. CO_2 concentration in gas wells: B-21, B-22, B-24, B-27 [5]

The monitoring of the chemical composition of the gas produced from the Borzęcin reservoir was performed from

1997 through 2011 and it confirmed the simulated results shown in Fig. 2. It should be emphasized that the Borzęcin injection programme was the first full scale, acid gas reinjection process of practical value carried out on a running production object as early as 1996. In 2004 a similar process was initiated in the Krechba field in Algeria by BP and Statoil [3].

The Poznań Trough Mega-structure and CO_2 Storage Potential Project

Permian structure of the Poznań Trough mega aquifer (Fig. 3) represents a great potential for long-term underground CO_2 storage covering 5000 km^2. The aquifer is naturally saturated by native hydrocarbon gases and its tightness is confirmed by the presence of many local gas accumulations in top areas of the structure.

The Poznań Trough is about 80 km long. The average depth of the Rotliegend water-bearing top formation is 2000÷3000 m.

It is known that in about 50 wellbores located there, the reservoir water is saturated with hydrocarbon gases. Some studies determined that the gas in water solution is 2,4 SC m^3 of gas in 1 m^3 of formation brine. It is estimated that gas resources (dissolved in aquifer) in the Poznań Trough Mega-structure can reach even 120 bn SC m^3 in the 5000 km^2 area (Fig. 4).

Studies performed in Polish Oil and Gas Institute confirmed that it is possible to inject the acid gases directly to the underlying water zone [4]. We performed PVT laboratory research on phase properties and carried out reinjection model simulations for the Borzęcin case. Based on our experience with reinjection of the acid gases in the Borzęcin field, it is expected that the process of dissolved hydrocarbon gases displacement by CO_2 will also take place in the Poznań Trough Mega-structure. This phenomenon results from the significant differences in the solubility of the natural hydrocarbon gases and CO_2 in the formation brine. This property is very interesting because, in practice,

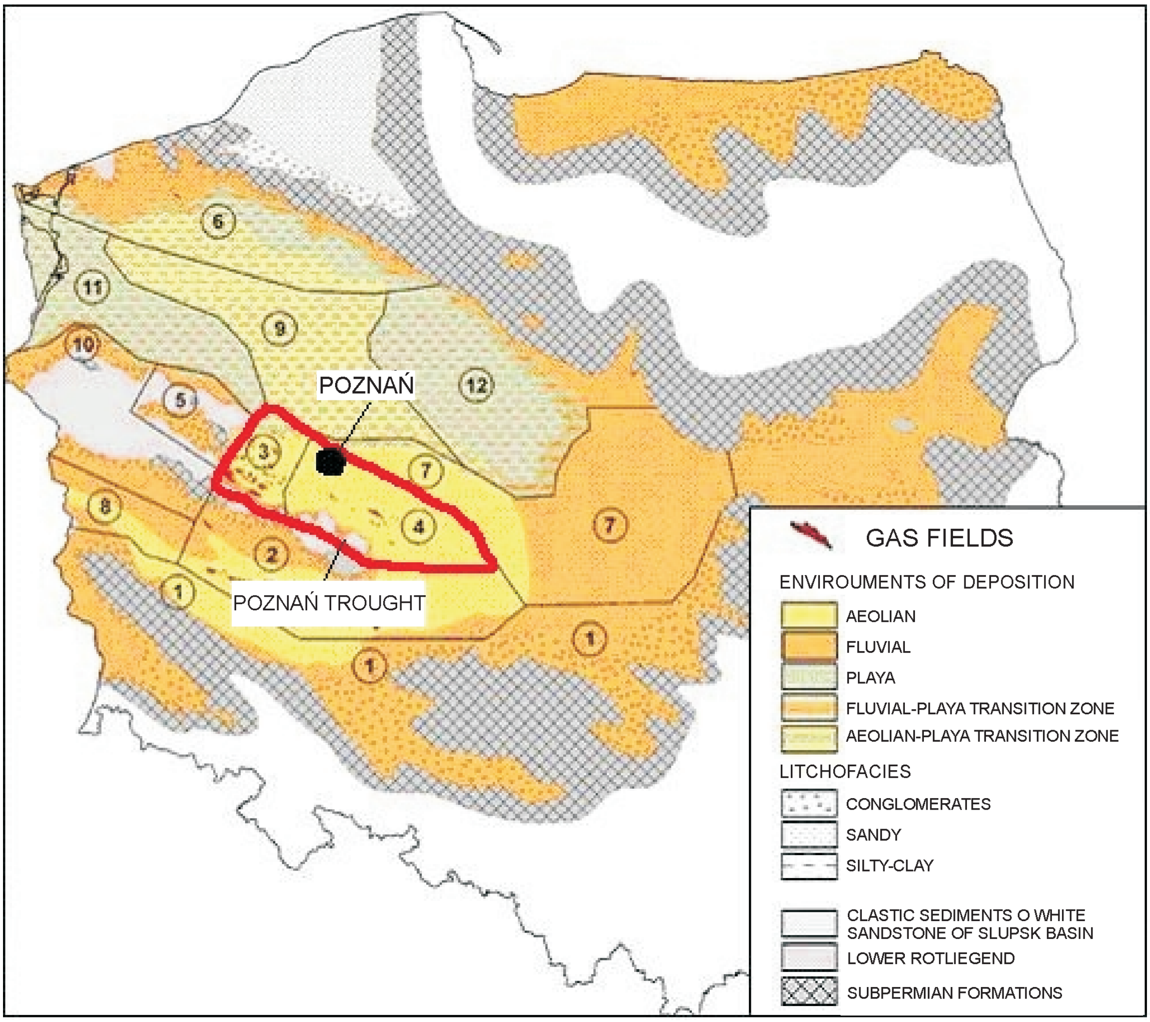

Fig. 3. Poznań Trough location on the Rotliegend map of Poland [6]

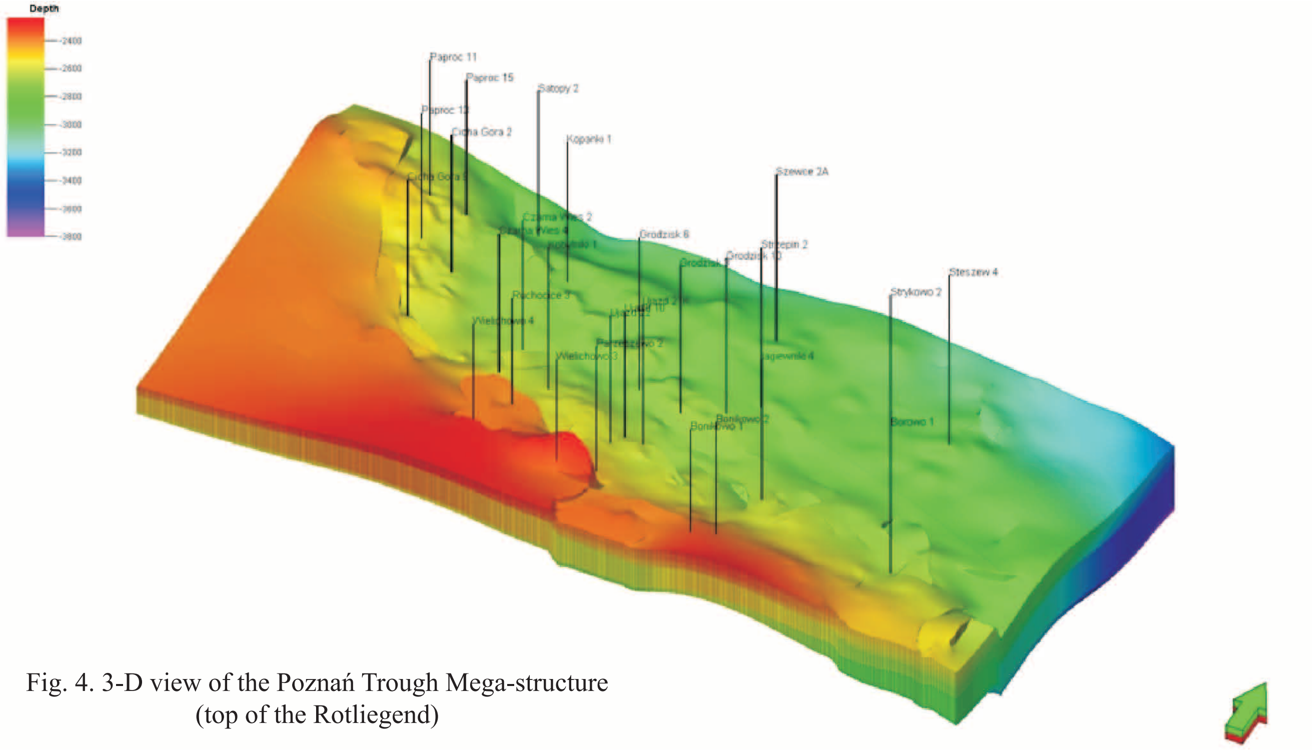

Fig. 4. 3-D view of the Poznań Trough Mega-structure (top of the Rotliegend)

it helps to minimize greenhouse effect and, at the same time, to replenish the gas resources in the gas cap with displaced gases originally dissolved in underlying water.

This effect can be observed in the results of reservoir simulation forecasts for CO_2 sequestration process in water bearing zones of the Poznań Trough Mega-structure. In the regions of the injected CO_2 significant reduction of methane dissolved in the brine can be seen as compared to those not reached by CO_2 (Fig. 5).

Methane displaced in water by CO_2 forms free gaseous phase, migrates upwards due to buoyancy effects, and refills structural traps of original gas reservoirs. This effect can be seen by comparing gas saturation distribution before and after CO_2 injection as shown in Fig. 6 and 7, respectively.

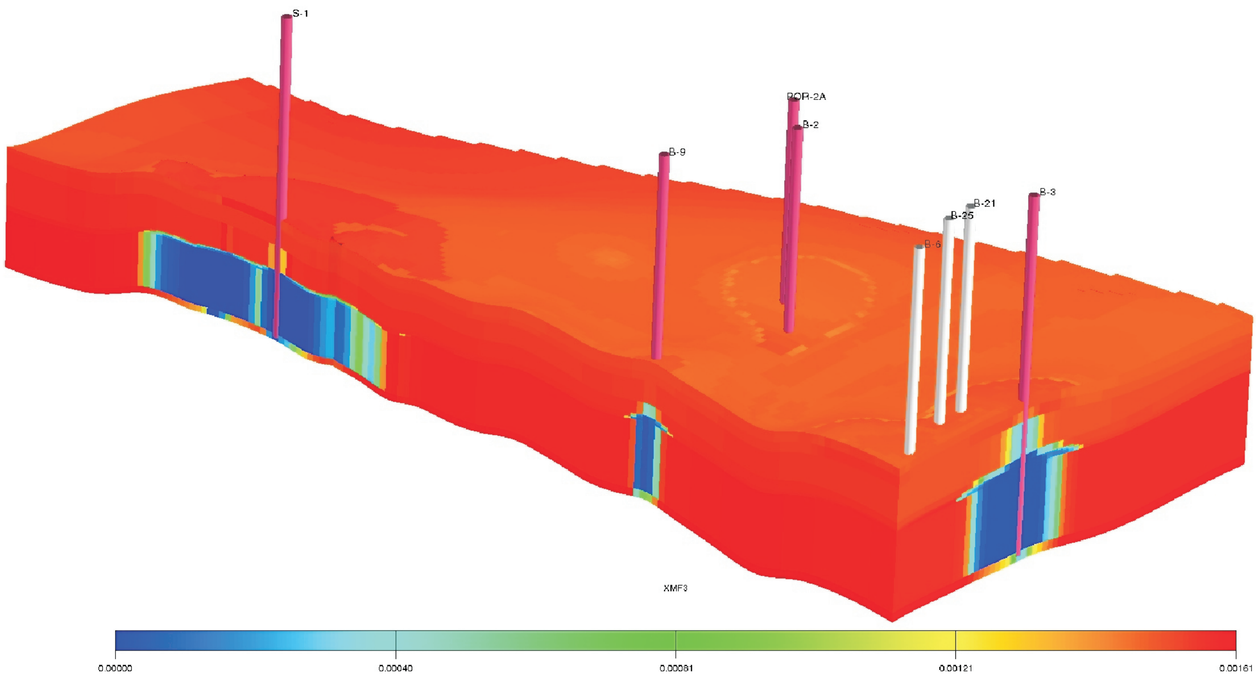

Fig. 5. Distribution of methane dissolved in brine after CO_2 injection into Poznań Trough Mega-structure [7]

Another advantage of the CO_2 sequestration in the Poznań Trough Mega-structure is the existing system of gas pipelines that can be used for CO_2 transport into the area of depleted gas reservoirs located within the Mega-structure.

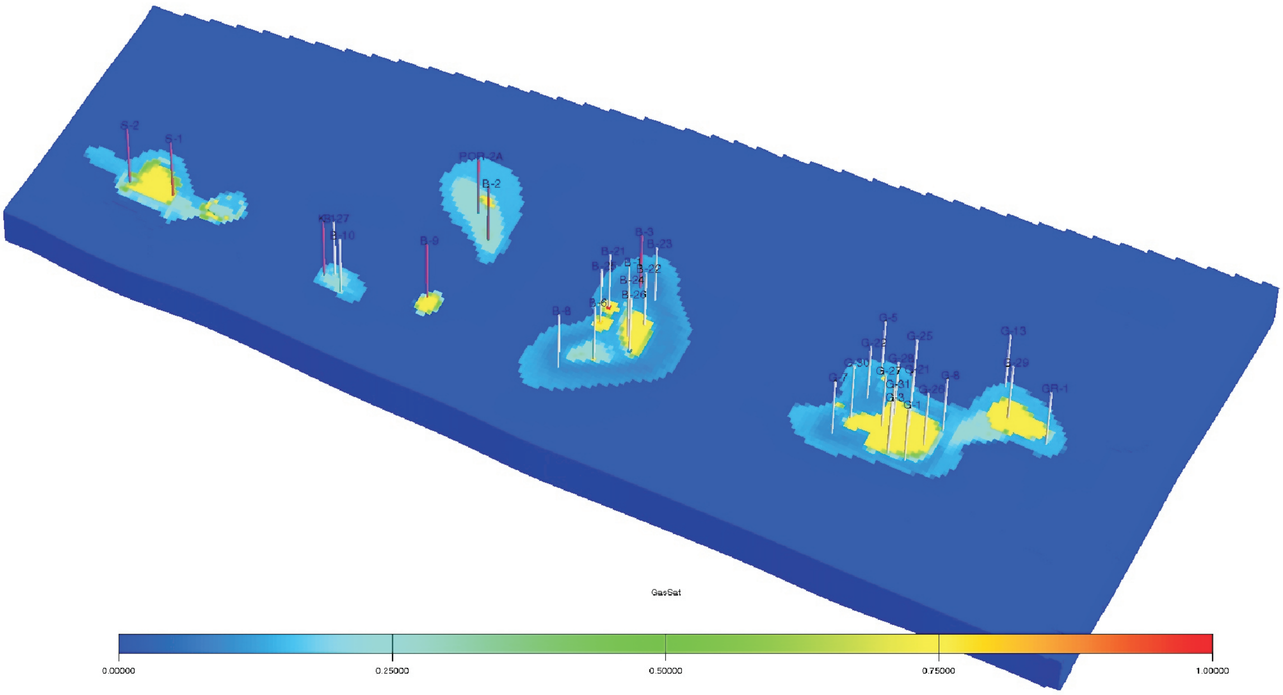

Fig. 6. Gas saturation distribution in top layers of the Rotliegend in Poznań Trough Mega-structure before CO_2 injection

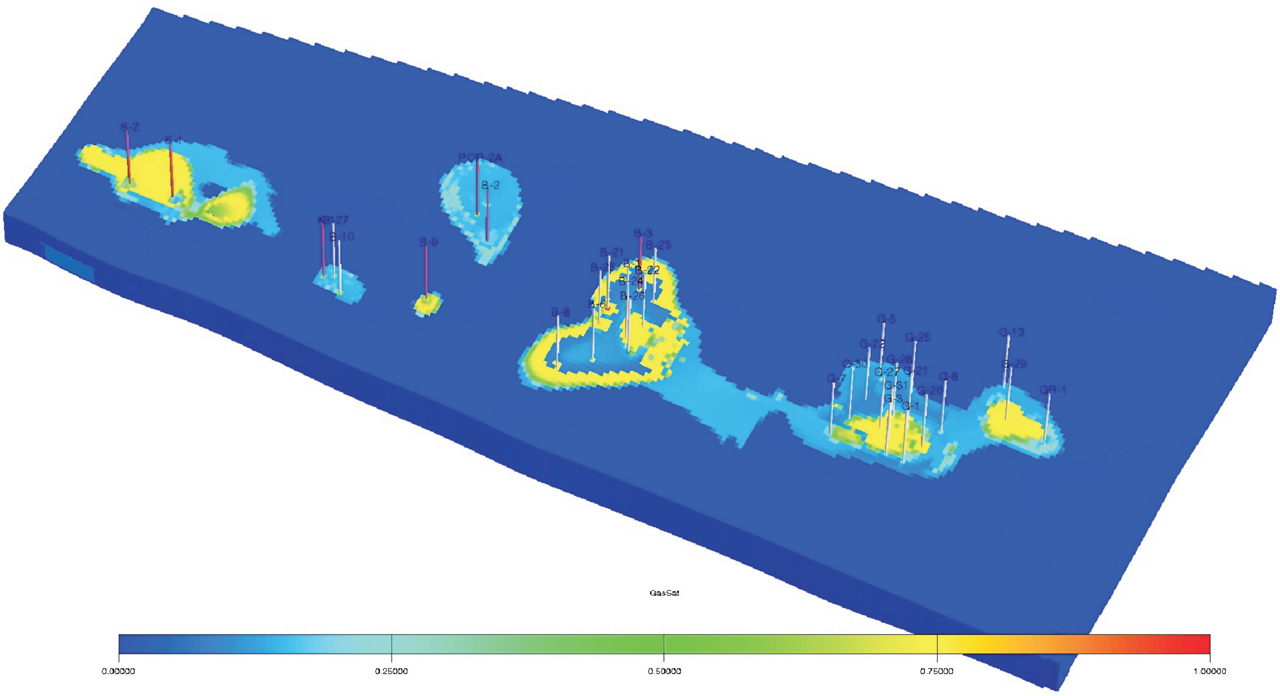

Fig. 7. Gas saturation distribution in top layers of the Rotliegend in Poznań Trough Mega-structure after CO_2 injection

Enhanced Oil Recovery Project for the Nosówka Oil Field

To analyze and assess predicted results of the CO_2 injection as a method of EOR applied to the Nosówka oil field a complete modelling and simulation project of the process was performed for this field [8]. The oil in the Nosówka field

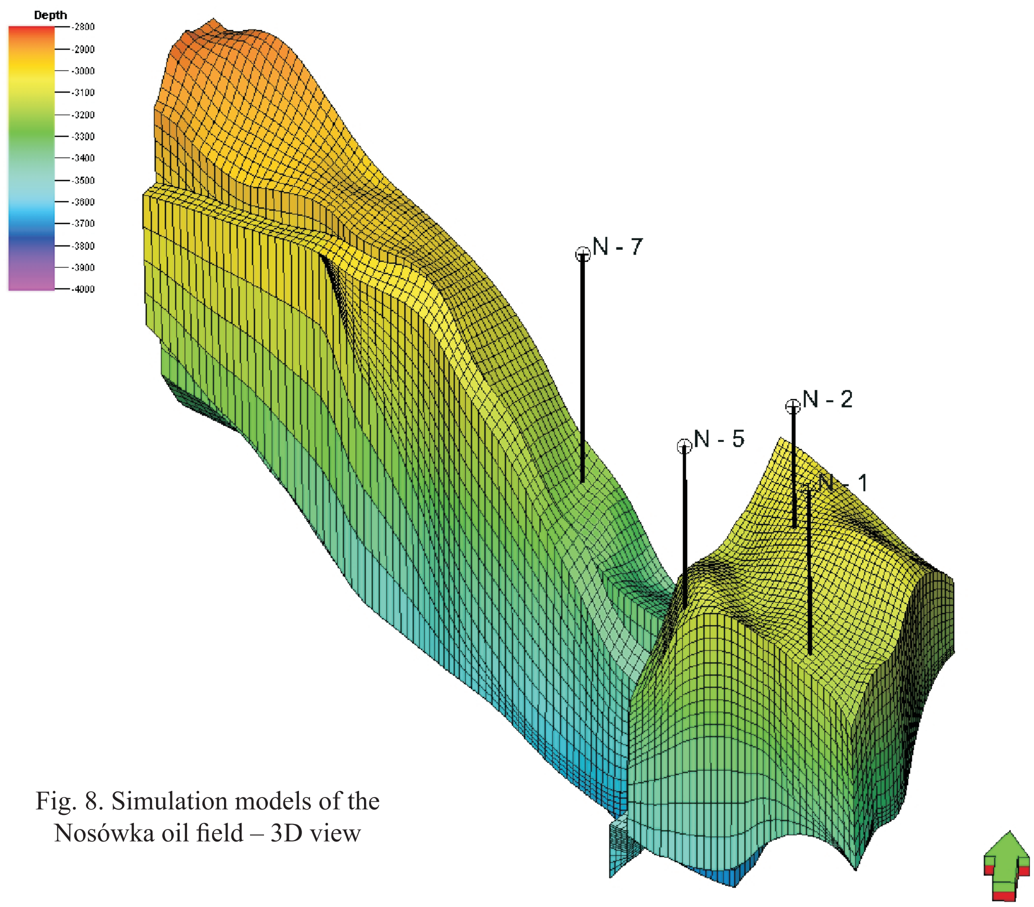

Fig. 8. Simulation models of the Nosówka oil field – 3D view

was trapped in the carbonate rocks: limestones and dolomite limestones of the Visian stage (lower Carboniferous unit).

The Nosówka field is located within the Carpathian flush in the southern region of Poland. It consists of two blocks: the central one (with wells: N-1, N-2, N-5) and the north-western one (with well: N-7). The reservoir boundaries are identified as the surrounding faults (Fig. 8). The above two blocks are hydro dynamically isolated from each other.

The geological model of the Nosówka structure was implemented in a reservoir simulation model that consists of 14 layers with 128 × 36 blocks each (Fig. 8). The model includes both the structural data and basic reservoir parameters in the form of their spatial distributions scaled-up to the simulation grid. The geological data was supplemented by reservoir fluid properties as the result of the solution of Soave'a-Redlich-Kwong equation-of-state for a given fluid composition (within the compositional simulator). Other input data, such as relative permeability, were calculated using standard correlations. The reservoir simulation model was successfully calibrated against historical production data (production rates, well pressures).

The simulation forecasts were performed for the following multi-scenario production schemes:

(1) natural production process (for comparison purposes) – scenario A,

(2) enhanced oil recovery with CO_2 injection – scenarios: B, C, D.

General production conditions were adopted according to the field operator requirements (including minimum and maximum production rates, minimum and maximum operating well pressures, maximum gas-to-oil ratios, maximum concentrations of CO_2 in produced gas).

Only the central block of the Nosówka structure was used in the EOR process. The three scenarios of EOR (B, C, D) corresponded to the following CO_2 injection schemes:

1. Scenario B – sequential conversion of producers (N-1, 2, 5) into injectors after their production ended, due to various limiting factors, injection rates followed the void age rate of production until the last producer ceased to produce, then the injection was continued until the original reservoir pressure was reached (358.8 bars) – Fig. 9 and 10.
2. Scenario C – injection before production. During the first stage of the process, the up-dip well (N-2) injected CO_2 at a constant rate until the original reservoir pressure was achieved. During the 2nd stage, the other wells produced until they met their limiting criteria.

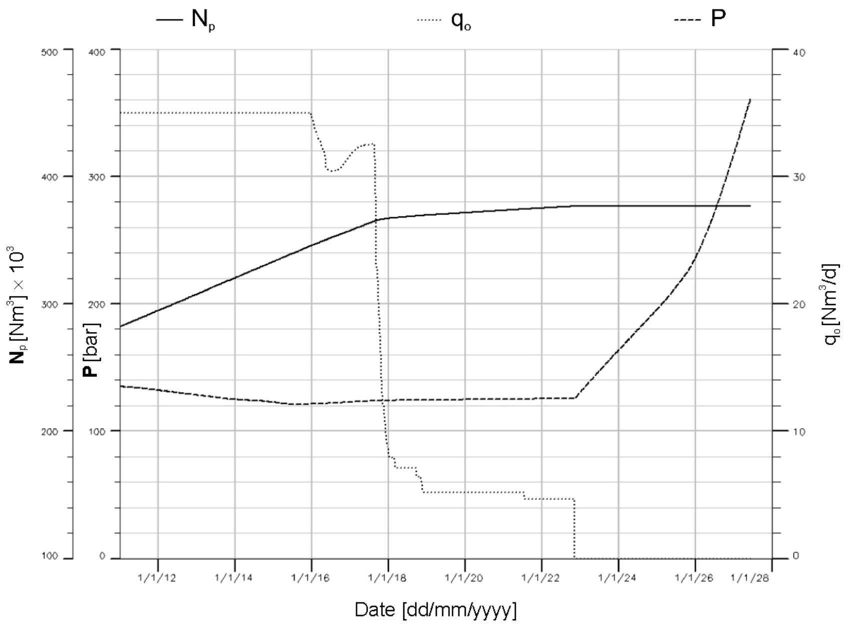

Fig. 9. Nosówka oil reservoir. Production forecast for CO_2 EOR. Scenario B. Total oil production, N_p, oil rate, q_o, and reservoir pressure, P

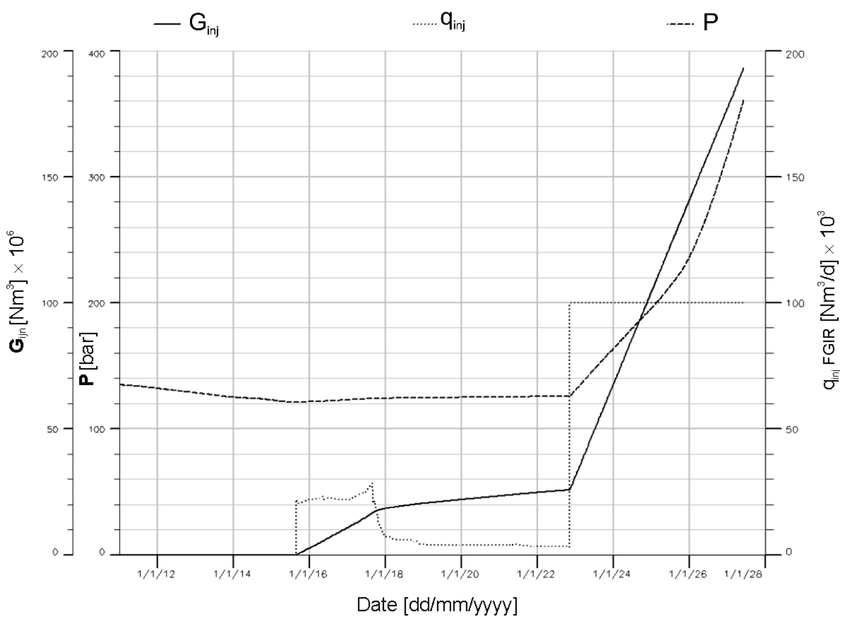

Fig. 10. Nosówka oil reservoir. Production forecast for CO_2 EOR. Scenario B. Total CO_2 injection, G_{inj}, injection rate, q_{inj}, and reservoir pressure, P

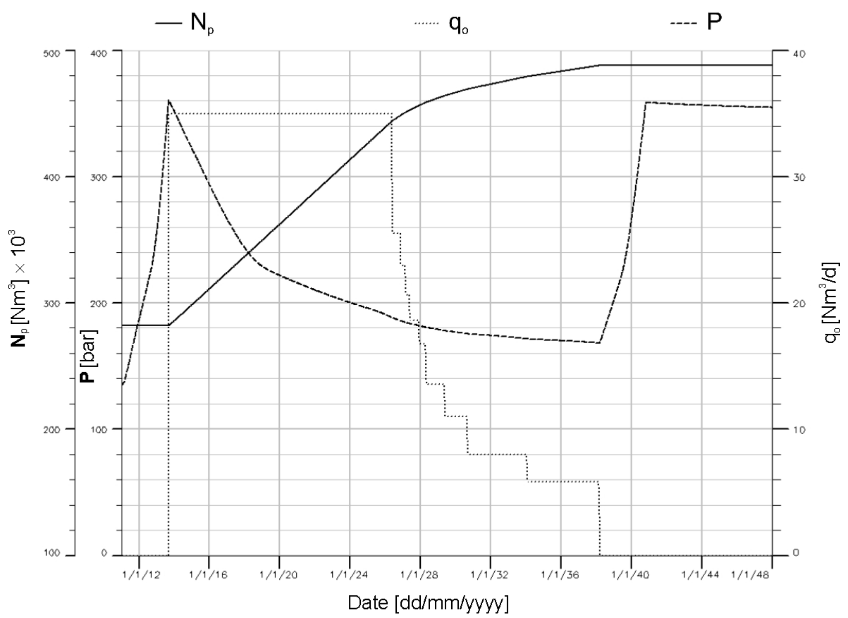

Fig. 11. Nosówka oil reservoir. Production forecast for CO_2 EOR. Scenario C. Total oil production, N_p, oil rate, q_o, and reservoir pressure, P

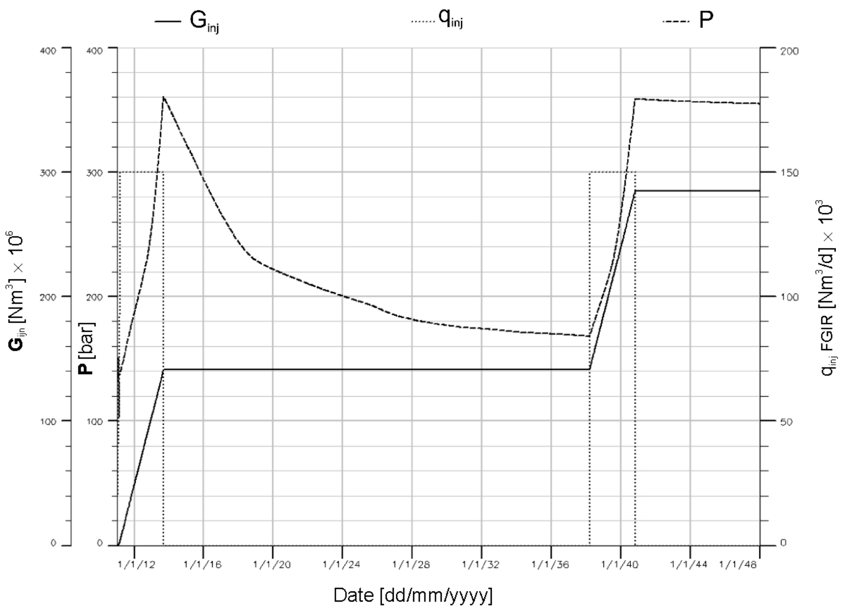

Fig. 12. Nosówka oil reservoir. Production forecast for CO_2 EOR. Scenario C. Total CO_2 injection, G_{inj}, injection rate, q_{inj}, and reservoir pressure, P

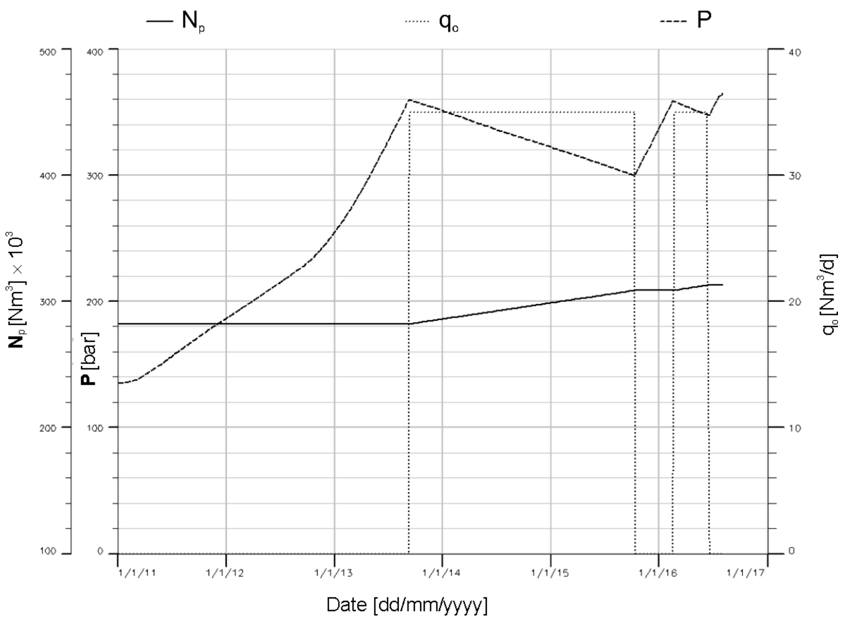

Fig. 13. Nosówka oil reservoir. Production forecast for CO_2 EOR. Scenario D. Total oil production, N_p, oil rate, q_o, and reservoir pressure, P

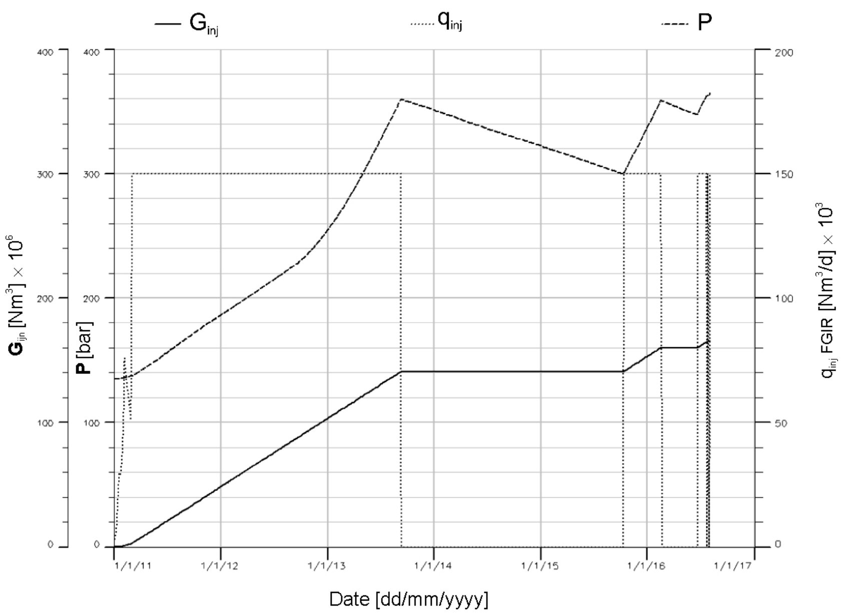

Fig. 14. Nosówka oil reservoir. Production forecast for CO_2 EOR. Scenario D. Total CO_2 injection, G_{inj}, injection rate, q_{inj}, and reservoir pressure, P

During the last, 3rd stage, the injector repeated the first stage – Fig. 11 and 12.

3. Scenario D – cyclic process with iterated injection – production stages, after each injection period as in scenario C, producers extracted oil until the reservoir pressure dropped from its original level to the oil saturation pressure (ca. 300 bars) – Fig. 13 and 14.

Comparisons of the results obtained for all of the above scenarios (Tab. 1) show that the most effective EOR process in the Nosówka field in realized by the CO_2 injection preceding the oil production stage (scenario C). This process increases the oil recovery factor from 47% up to 64% and results in the CO_2 sequestration capacity of ca. 550 kilotons. Other injection schemes, where injection and production are simultaneous or cyclic, are less effective.

Table 1. Nosówka oil reservoir. Production forecasts for CO_2 EOR

Scenario	Total oil production [× 1000 SC m^3]	Predicted oil production [× 1000 SC m^3]	Total CO_2 injection		Recovery factor
			[× 1000 ton]	[× 10^6 SC m^3]	
A	357.9	76.0			0.47
B	376.6	94.7	370	193	0.49
C	**487.9**	**206.1**	**546**	**285**	**0.64**
D	312.6	30.7	316	165	0.41

Literature

[1] Lubaś J., Krępulec P.: *Reinjection of sour gases as a new way to manage acid deposits*. "Nafta-Gaz" nr 6, 1999.

[2] Lubaś J.: *First in Europe small industrial plant for CO_2 sequestration*. "Nafta-Gaz" nr 1, 2008.

[3] Mathieson A., Midgley J., Dodds K., Wright I.: *CO_2 sequestration monitoring and verification technologies applied at Krechba*, Algeria. The Leading Edge. Febr., 2010.

[4] Lubaś J.: *The pioneer experience of Poland in CO_2 sequestration*. Przegląd Geologiczny, vol. 55, nr 8, 2007.

[5] W. Szott, A. Gołąbek, K. Miłek: *Simulation studies of acid gas sequestration in aquifers underlying gas reservoirs*. Prace INiG nr 165, Kraków 2009.

[6] Lubaś J., Warchoł M., Krępulec P., Wolnowski T.: *Greenhouse gas sequestration in aquifers saturated by natural gases.* XXI World Gas Mining Congress. Gospodarka Surowcami Mineralnymi. Tom 24. Kraków 2008.

[7] Szott W., Łętkowski P., Gołąbek A., Miłek K., Rychlicki A.: *Modelowanie dynamiczne procesów zatłaczania CO_2 do składowiska. Struktura Niecki Poznańskiej*. Praca INiG. Zadanie 1.1.16. Narodowego Programu Sekwestracji wykonanego na zamówienie Ministra Środowiska, 2011.

[8] Szott W., Łętkowski P., Miłek K., Gołąbek A. Rychlicki A.: *Modelowanie dynamiczne procesów zatłaczania CO_2. Złoże Nosówka.* Praca INiG. Zadanie 1.1.16. Narodowego Programu Sekwestracji wykonanego na zamówienie Ministra Środowiska, 2010.

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