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# Effects of Acid Gas Reinjection on $CO_2$ Concentration in Natural Gas Produced from Borzęcin Reservoir

The first Polish installation for the reinjection of acid gases started to run on the Borzęcin gas reservoir operated by Polish Oil & Gas Company. The installation was designed based on the results of an Oil & Gas Institute (INiG) research.

The gas injected into the Borzęcin structure contains approximately 60% of $CO_2$ and 15% of $H_2S$.

It should be emphasized that the Borzęcin injection program 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 on a larger scale was realized in the Krechba field in Algeria by BP and Statoil [1].

Borzęcin is considered to be a unique experimental plant which allows us to investigate the acid gas sequestration process. Contrary to other large reservoirs – the small bulk volume of the onshore Borzęcin structure enables us to analyze the sequestration process in a short time scale.

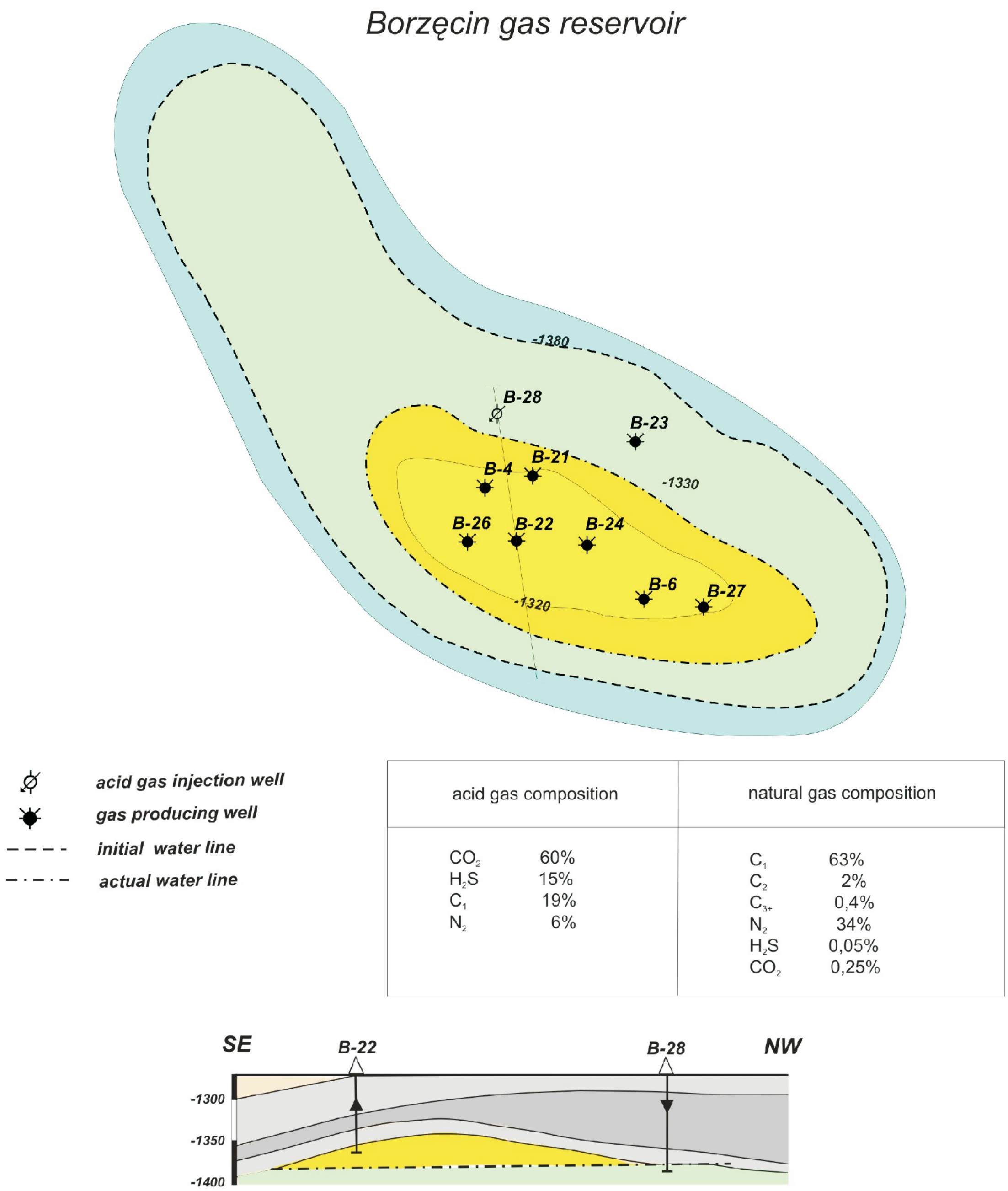
## Production history of the Borzęcin gas reservoir

The Borzęcin gas reservoir was discovered in 1969; it is located in the region of the Zielona Góra basin in the southern Pre-Sudetan Monocline. The Borzęcin structure includes anticline with two local uprisings. The two portions of the Borzęcin reservoir are composed of the limestone Zechstein and Rotliegendes formations and are similar but the latter has a little bit smoother structure. The first accumulation of gas was discovered at the depth of 1380 m in an interval which included Rotliegendes and carbonate Zechstein horizons. Both pay horizons are hydro dynamically connected. The reservoir is confined by overlying Zechstein strata from the top and by underlying water from the bottom. The Borzęcin site is the only reservoir discovered so far in Zechstein limestone and Rotliegendes formations of the Polish Lowland which contains gas with high $H_2S$ concentration.

The initial production rate from the Borzęcin reservoir was low due to the high $H_2S$ content (0.4÷0.7 mln SC $m^3$ per year). Later on, the gas production rate was increased to 290 mln SC $m^3$ per year in 1977 after the amine-type gas desulphurization plant started to work. Eight wells, including Ż-1, B-1, 4, 6, 7, 10, 11 and 12, produced until 1985. The decreasing production rate from the Borzęcin reservoir had forced the operator to drill ten additional wells (B-21 – 30) among which Borzęcin-28 was the injector (see Fig. 1).

The production history of the Borzęcin reservoir indicates that it is producing in volumetric regime. Gradual increase of water cut, water flooding of subsequent wells, and a simultaneous decrease in reservoir pressure indicate that water is flowing into the reservoir gradually and passively. The volumetric production regime of the Borzęcin reservoir is also confirmed by a linear relation between reservoir pressure and the volume of gas produced. The geological reserves of the Borzęcin reservoir are estimated as $4.7 \cdot 10^9$ SC $m^3$ of gas.

Up to 1996 the acid gases (by-product of amino desulphurization plants) were burnt in special furnaces and combustion gases were released to the atmosphere in the form of $CO_2$ and $SO_2$. During these years $3.5 \cdot 10^9$ SC $m^3$




| acid gas composition | | natural gas composition | |
|---|---|---|---|
| $CO_2$ | 60% | $C_1$ | 63% |
| $H_2S$ | 15% | $C_2$ | 2% |
| $C_1$ | 19% | $C_{3+}$ | 0,4% |
| $N_2$ | 6% | $N_2$ | 34% |
| | | $H_2S$ | 0,05% |
| | | $CO_2$ | 0,25% |

Fig. 1. Structural map of the Borzęcin reservoir with the vertical cross section and chemical composition of acid gas and produced natural gas

of gas with $H_2S$ concentration equal to 1 g $H_2S$/SC $m^3$ were produced, which means that $3.5 \cdot 10^3$ tons of sulfur were emitted to the atmosphere. Growing requirements concerning pollution control and technical problems related to discharging $CO_2$ and $SO_2$ into the atmosphere (40 m long flares collapsed because of corrosion and wind) forced the operator to use the new gas-utilization technology introduced by INiG during the 1993/1994 period. The water bearing horizon of Rotliegendes formation (1470÷1565 m) in B-28 well was selected for acid gas injection purposes.

Gas reinjection started in January 1996. The injected gas composition was: 50÷60% of $CO_2$, and about: 15% of $H_2S$, 19% of $CH_4$, 15% of $N_2$ and some gaseous residues. The gas injection rate was 40 SC $m^3$ per hour. Computer simulation of the gas displacement process indicated that the increase of acid gas concentration in produced gas was expected after 8 years of the injection process i.e. in 2004. Indeed, results of gas analyses carried out in 2003 showed $CO_2$ content increase in gas produced from the B-4 well – this confirmed the necessity of constant monitoring of the gas composition (Tab. 1).

Tab. 1. The $CO_2$ concentration in natural gas produced from the Borzęcin reservoir for the period 1998–2011

| | Wells, $CO_2$ concentration [% mol] in natural gas in particular years | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | Z-1 | B-4 | B-6 | B-21 | B-22 | B-24 | B-27 | B-29 | B-30 |
| 04.98 | 0.1030 | 0.1380 | 0.2840 | 0.1582 | 0.2932 | 0.2272 | 0.2896 | 0.0690 | |
| 06.03 | 0.2770 | 0.7520 | 0.3540 | 0.2960 | 0.3420 | 0.3080 | 0.3610 | 0.1250 | 0.1480 |
| 12.04 | | 1.4150 | 0.3480 | 0.2780 | 0.3310 | 0.3530 | 0.3630 | | |
| 03.06 | | | 0.2499 | 0.2881 | 0.3492 | 0.2593 | 0.3046 | | |
| 10.06 | | | 0.3724 | 0.3052 | 0.3802 | 0.3226 | 0.3721 | | |
| 02.09 | | | | 0.2945 | 0.4119 | 0.3053 | 0.4119 | | |
| 07.09 | | | | 0.3628 | 0.4817 | 0.3034 | 0.4206 | | |
| 03.10 | | | | 0.2975 | 0.4569 | 0.2258 | 0.4269 | | |
| 11.10 | | | | 0.2908 | 0.4968 | 0.3267 | 0.3680 | | |
| 05.11 | | | | 0.2928 | 0.4287 | 0.3612 | 0.4620 | | |
| 09.11 | | | | 0.3327 | 0.4635 | 0.3640 | 0.4711 | | |
| Increment of $CO_2$ | | 1.2770 | | 0.1745 | 0.1703 | 0.1368 | 0.1815 | | |

Note: blue color- abandoned wells, red color – chromatographic analyses performed between 2006-2011.

## Results of chromatographic analyses of gas from the Borzęcin gas wells

The change in concentration of $CO_2$ in natural gas from the Borzęcin reservoir for the period 1998–2011 is shown in Tab. 1 and Fig. 2. As shown here we can observe the gradual increase of $CO_2$ in gas produced from the Borzęcin reservoir. The increase of $CO_2$ concentration in produced gas as opposed to $H_2S$ is observed first because its concentration in re-injected gas is about 4 times in volume larger than $H_2S$.

Uncertainty of measurement results shown in Table 1 and Figure 2 was estimated according to standard deviation which is between 0.0016 and 0.0024.

The largest increase of $CO_2$ concentration (1.2770%) was observed in B-4 and in 2004 this well was capped. No relation was found between the increase of $CO_2$ concentration, the distance to injection well and volume of gas produced from the well being considered. $CO_2$ concentration increase from 0.138% to 1.415% in gas produced from B-4 well, which was nearest to the injection well (637 m), persuaded the operator to abandon this well. The rate of increase of $CO_2$ concentration observed in more distant wells is much smaller and we do not anticipate that it will affect the production of the Borzęcin reservoir in the near future. The localization of injection and production wells for the Borzęcin reservoir is shown in Fig.1.

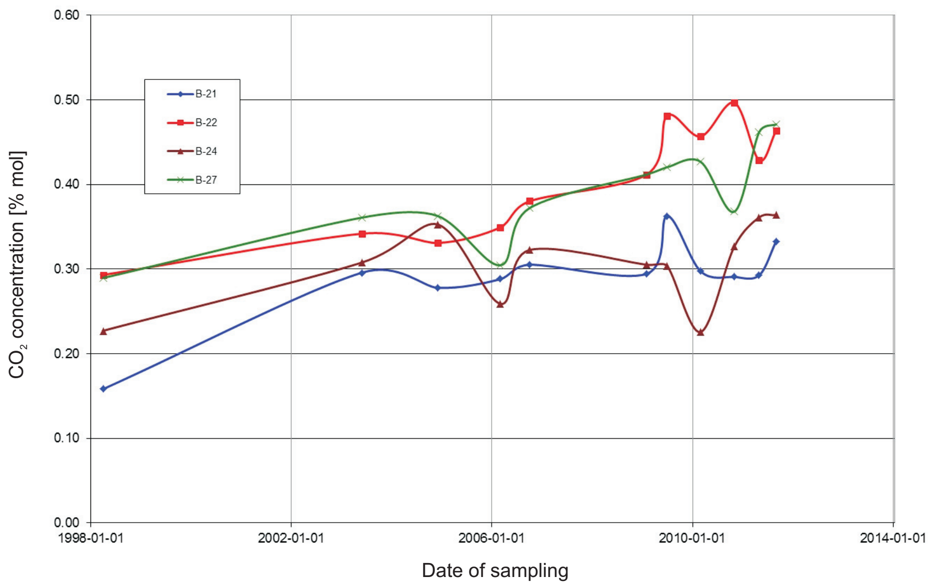



Fig. 2. $CO_2$ concentration [% mol] in the natural gas from the Borzęcin reservoir production wells

### Reservoir simulation model of the Borzęcin structure and its predictions

The geological structure of the Borzęcin gas reservoir together with the underlying aquifer formations was modelled for simulation purposes of the reservoir processes taking part during the acid gas reinjection [2]. The model was verified and history matched against the production data including bottom hole pressure measured in all producing wells as well as $CO_2$ concentration data for the gas produced from the wells. An example of the simulation match of the concentration data for a selected producing well is shown in Fig. 3.

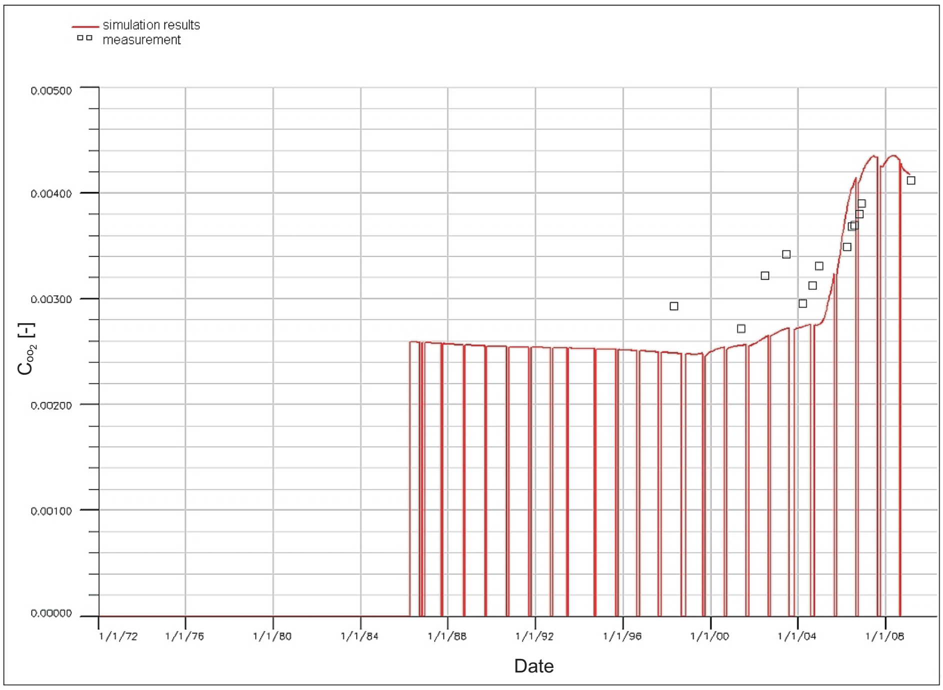



Fig. 3. Borzęcin Gas Reservoir. Example of simulation matches to measured data of $CO_2$ concentration in a production well

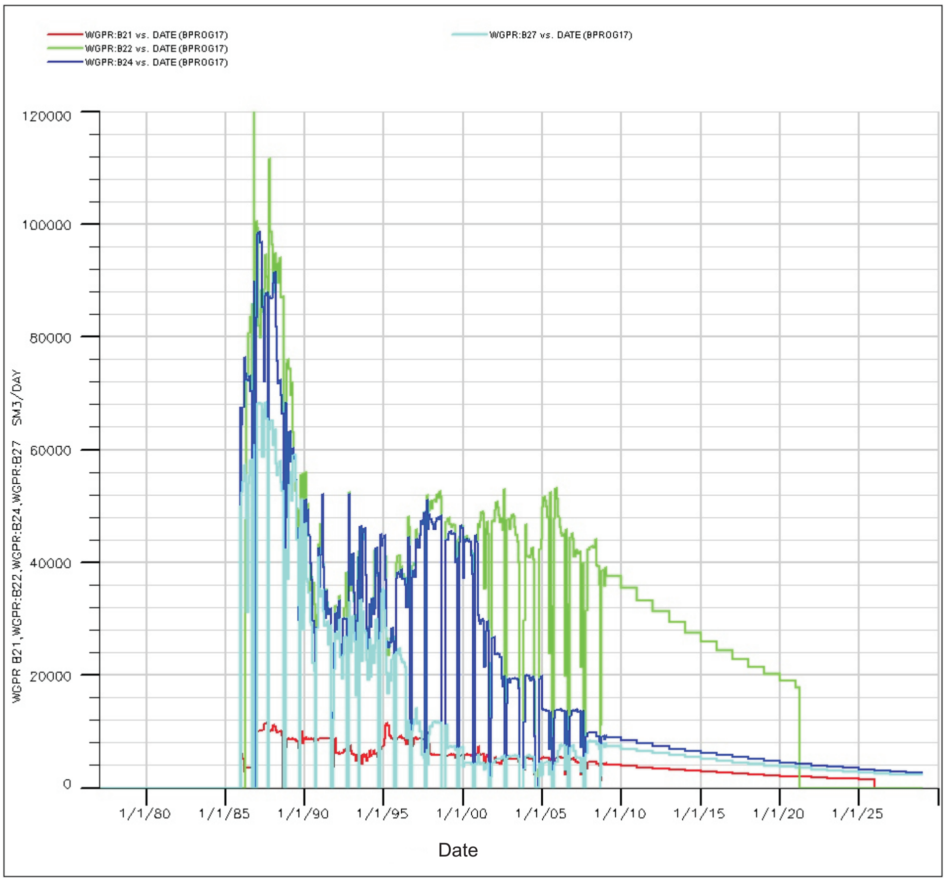



Fig. 4. Borzęcin Gas Reservoir. Simulation predictions of future reservoir performance

Then the model was used to predict the future performance of the Borzęcin gas reservoir. The production rate profile (Fig. 4) for all the producers showed a typical decline and persistent production of most (three out of four) wells despite a relatively strong water encroachment into the gas bearing zone resulting in partial pressure restoration (Fig 5). Most interestingly, complex interplay between the water encroachment and injected $CO_2$ migration within the reservoir resulted in quite moderate contamination of the produced gas by the injected $CO_2$ which concentration in the produced stream did not exceed 0.5%. This effect can be seen in Fig. 6 where $CO_2$ concentration in the gas produced from all the wells as calculated by the simulation model is presented. The simulation results are consistent with measured concentration data obtained recently – see Fig. 7. Based on these results it may be safely concluded that the production process can be prolonged to as far as 2028 without contamination risk from the reinjected $CO_2$.

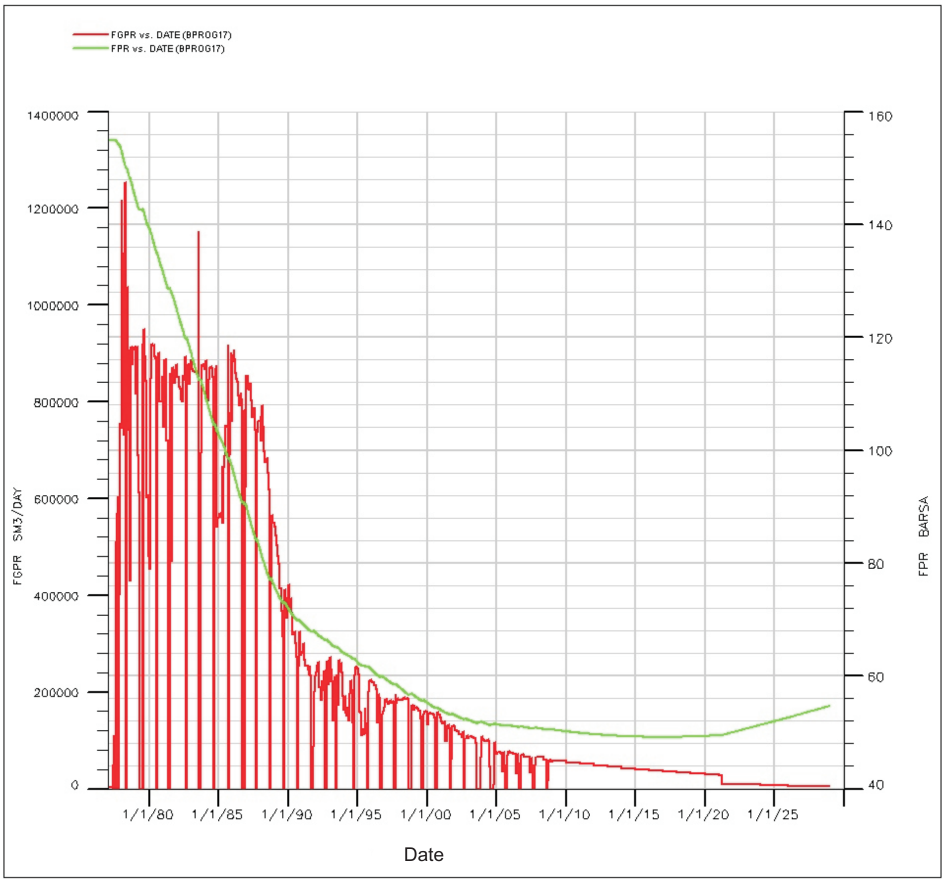



Fig. 5. Borzęcin Gas Reservoir. Past and future gas production rate and average reservoir pressure

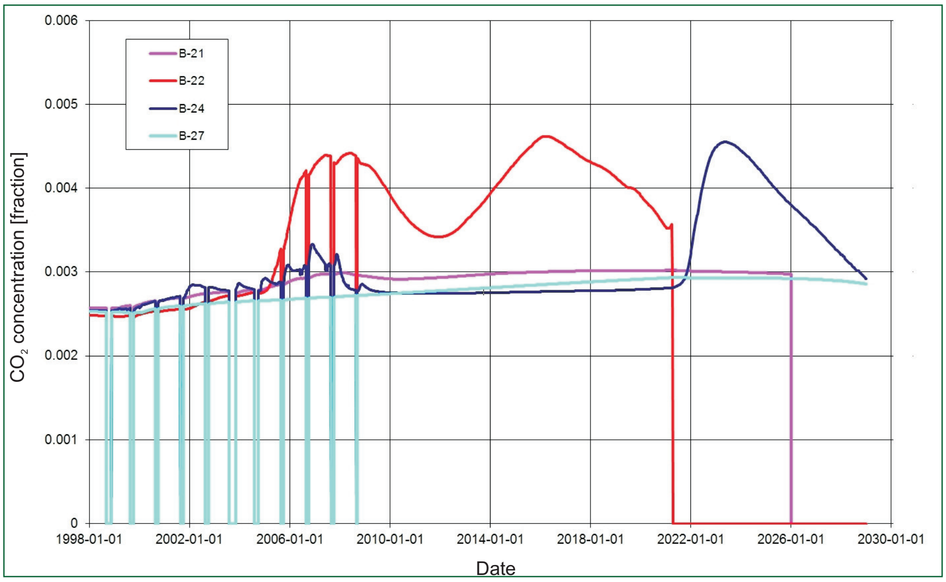



Fig. 6. Borzęcin Gas Reservoir. Predictions of the $CO_2$ concentration in gas production from individual wells

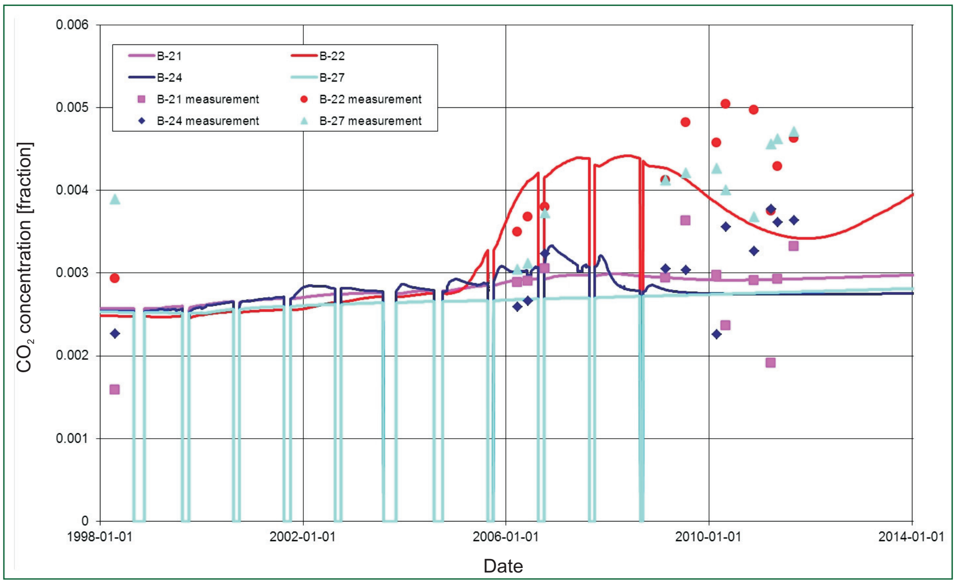



Fig. 7. Borzęcin Gas Reservoir. $CO_2$ concentration in gas production from individual wells. Simulation results and measured data

## Conclusions

1. Measurements of gas composition were carried out for gas produced from the Borzęcin reservoir with the acid gas injection into the water horizon underlying the gas pay zone.
2. Increase of acid gas components (in particular $CO_2$) in gas produced from the Borzęcin reservoir is observed during this period. The greatest increase of $CO_2$ concentration (1.277%) was observed in B-4 well. The lowest increase of $CO_2$ concentration was observed in B-24 well (0.1368%).
3. The simulation model of the Borzęcin structure was constructed and positively verified. The future performance of the reservior as predicted by the model shows quite low $CO_2$. contamination (< 0.5%) of the produced gas.

### Literature

[1] Mathieson A. Midgley J., Dodds K., Wright I.: *$CO_2$ sequestration monitoring and verification technologies applied at Krechba, Algeria*. The Leading Edge. Feb., 2010.
[2] Szott W. Gołąbek A., Miłek K. Simulation studies of acid gas sequestration in aquifers underlying gas reservoirs. Prace nr 165 Instytutu Nafty i Gazu. 2009.

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