Carbon dioxide sequestration by injection to various geological reservoirs

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CO_2 sequestrácia pri vstrekovaní do geologických šruktúr

The sequestration of carbon dioxide in a geological formation is still in the design phase in Poland. The experimental project with the Enhanced Coal-Bed Methane (ECBM) in Silesia ("Recopol") is in a pilot phase. The other carbon dioxide sequestration combined with the Enhanced Oil Recovery (EOR) is designed for the "Jastrzabka Stara" field. All possible types of sequestration of carbon dioxide in Poland are discussed and presentedm, the present states of sequestration projects are included.

***Key words**: Carbon dioxide, sequestration by injection, EOR*

Introduction

The underground storage of carbon dioxide may be a potential technology to decrease of greenhouses gases emission, usually from industry sources (e.g. power plants, refinery plants, and chemical factories).

There is a number of existing technologies, including chemical absorption, adsorption, cryogenic processes, and membranes, that can separate carbon dioxide (CO_2) from flue gases emitted during the power plant operation. The sequestration of CO_2 is a complex process of capture, transport and deep injection into the geologic formation (including the ocean, aquifers, and depleted oil and gas wells). The geologic researches may optimize the sequestration process and the forecast of the CO_2 migration process in the underground storages. Because the sequestration is an expensive process – various economical variants are proposed. One of best is the enhanced oil recovery with CO_2 (EOR-CO_2), the second is the process of enhanced coal bed methane (ECBM). The overall costs of sequestration are from 5 \$ to 20 \$ (or more) for tone of CO_2. The specific costs are a function of the capture cost, transport cost, and the properties of the geologic storage.

Carbon Capture Technologies

The following technologies are available for capturing of carbon dioxide: the chemical absorption, the cryogenic process, the physical absorption, the membrane technologies:

- **Chemical absorption**—Currently, all commercial power plants that capture CO_2 use the processes based on the chemical absorption with a solvent. In these processes, a solvent, such as monoethanolomine (MEA), is used in a scrubbing system to remove CO_2 from the flue gas stream (IEA, 2002).
- **Adsorption**—Adsorption methods involve a physical attraction between the gas and the active sites on a solid. This process contrasts with absorption, which causes a chemical reaction to capture CO_2. These methods are used commercially in process industries and may be applicable to power plants in a future. (IEA, 2002).
- **Cryogenic processes**—Cryogenic systems are low-temperature processes which separate CO_2 directly or through a solvent. CO_2 can be physically separated from other gases by condensing it at low or cryogenic temperatures. Cryogenic processes produce liquid CO_2, which is immediately ready for the transport to a disposal site. (IEA, 2002).
- **Membranes**—This technology involves a membrane which selects and removes certain components from a gas stream because of an absorption liquid on one side of the membrane. This approach is limited

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by the size of existing membrane separators, but does have the advantage of very high selectivity (IEA, 2002).

CO2 Transportation

Pipelines were accepted as a solution for transporting CO_2 in all existing projects of secondary methods CO_2-EOR. It is considered to transport CO_2 in the condensed form in tanks adapted to the LPG transport. In case of the pipeline transportation, the higher pressure than the critical pressure is applied (i.e. 7.4 MPa). In general, the flow pressure of CO_2 varies between 8 and 17 MPa.

Enhanced Oil Recovery (EOR)—An option for the sequestration are depleted but still active fields where the oil recovery could be improved by the injection of CO_2. The enhanced oil recovery (EOR) would have the advantage of being commercially active at this time, as over 80 % of commercially used CO_2 is for EOR (DOE, 1999). Beginning in Texas in 1972, CO_2 has been injected to improve the oil production for years. The injected CO_2 works to improve the oil production by two major mechanisms. First, it works to displace the oil, which is then pumped away. The injected CO_2 also dissolves in the oil, which causes the oil to be less viscous and the flow more easy (DOE, 1999). The amount of CO_2 that can be utilized for EOR and related applications is small compared to the total CO_2 emissions, and CO_2 can currently be supplied from natural sources at about one-third the cost projected for CO_2 captured from power plants (Herzog et al, 1997). Consequently, there is no real incentive to use CO_2 captured by power plant. Presently captured CO_2 would have to cost less than $25/t for the most efficient EOR applications to be economic (IEA, 2002). Overall, the amount sequestered from EOR may not be large, but a valuable operational experience can be gained that would benefit the geologic sequestration in other types of formations (DOE, 1999).

Enhanced Coalbed Methane Production—Coal formations could sequester CO_2 while also enhancing the production of natural gas. Injecting CO_2 into coal formations causes the adsorption of CO_2, which leads to the desorption of methane, improving the natural gas production. The coal bed conditions, however, must be favorable for the application of CO_2 enhanced methane production to be safe and economical. For a success, the projects need a favorable geology with a sufficient permeability, a cheap CO_2 availability, and an adequate gas demand (DOE, 1999). Currently, a couple of projects are testing this method for enhancing the coal-methane production. The initial results show that the methane recovery is improved with the CO_2 injection and that it may be profitable (IEA, 2002).

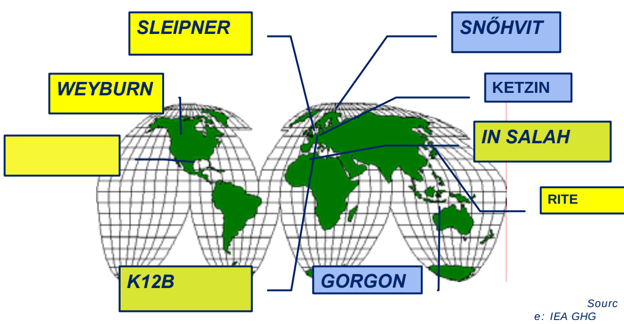

Fig. 1. Demonstration Project EOR-CO2 sequestration

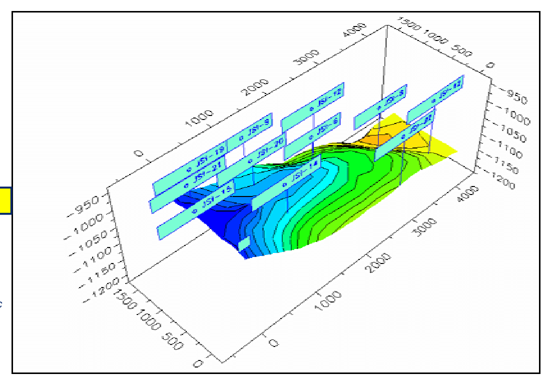

Fig. 2. The 3D structure view of the Jastrząbska Stara oil reservoir based on the structural map

CO_2 injection processes

The CO_2 injection into geological structures is performed with the use of injection wells. The well location should be optimized. Injected CO_2 tends to migrate upward in the reservoir structure. As a result, before the main injection is performed, it is recommended to design the pilot injection operation. The leak proof of wells, state of its cementation, the proper thickness of pipe walls and the suitable well depth are also relevant. The pipeline walls should be corrosion-resistant.

Geological conditions of the structure designated for the CO_2 storage

The geological structure designated for the underground CO_2 storage should be appropriately tight. In case of the designation for the CO_2 storage in abandoned coal mines, it is necessary to take into account that coal adsorbs CO_2 two times more intensively than methane. The relevant parameter considered in the CO_2 storage is its density. Taking into consideration the pressure gradient (approx. 10 MPa/km) and the temperature gradient (30 ^{0}C/km) the CO_2 density sharply varies at the depth between 500 and 1000 m. For the depths below 1000 m the CO_2 density changes between 600 and 700 kg/m^3. In general, in the reservoir conditions the CO_2 density is considerably lower than the water density; so it tends to occupy top parts of the structure. Simultaneously, while contacting water CO_2 dissolves in water and relocates with it. However, this relocation is very low and, according to the computer simulations, it is in a region of few kilometers within 5 thousands years. Because of a high tendency of the CO_2 migration into upper parts of a porous rock, the structure should be tight.

The CO_2 injection process should be precisely tracked. There are two methods of tracking. These are: the computer simulation performing and the geophysical research performing. The efficiency of geophysical research depends mainly on the contrast of physical properties of CO_2 and reservoir fluids, the lithology of storage layer, the reservoir pressure and its changes and the distance between wells.

Examples of Polish CO2 sequestration projects

Example 1 Sequestration during the oil reservoir production – Jastrzabka Stara Reservoir

A number of test calculations calibrating the reservoir model was performed (Siemek et al, 2006) :

1. Particularly, the numerical recombination of the reservoir fluid properties was carried out.
2. Minimum miscibility pressure was determined (between 139 and 156 bars).
3. Because of lack of data concerning the reservoir tightness at the pressure exceeding 130 bars, all calculations were limited to the CO_2 injection peak-value of 130 bars.
4. Shortage of the confining reservoir pressures did not allow to calibrate the model precisely. Overall geological reservoirs were performed and the reservoir pressure course was restored partly.
5. Three possibilities of the CO_2 injection into the Jastrząbka Stara reservoir, that basically varies in the amount of injected CO_2, were selected.

It was assumed that carbon dioxide will be injected into the JSt-12 well, in a liquid or supercritical form. Considering conditions in the well, it is believed that at the bottom of the injection well supercritical conditions are present. Supercritical carbon dioxide displaces oil and dissolves in oil and water. A part of carbon dioxide through the hydrocarbon phase displace and dissolve in oil causing a decrease of hydrocarbon system viscosity and an increase of the pressure in the injection area in the vicinity of the JSt-12 well.

Because the distance between the JSt-8 JSt-12 wells exceeds 1.1 km in the straight line, a carbon dioxide breakthrough to the exploitation JSt-8 well will not be done by 2020. It is noticed an increase of the reservoir pressure – at first in the area direct around the JSt-12 well, and later a further increase of the pressure in the reservoir . The increase of the pressure affects the exploitation of the whole reservoir, because the Jastrząbka Stara well does not have good hydrodynamic properties.

The vertical cross-section J-8 vs. J-12 displaying the CO2 molar concentration distribution (mol/m3) at the end of 2007-2014 is shown in the Fig. 3. The calculations show a slow moving of the front towards the JSt-8 well. The distance between the wells exceeds 1100 m in the straight line; because of this, no breakthrough effect was observed. It is noticed an increase of the efficiency of exploited oil in the JSt-8 well. Fig. 4 shows the flow capacity of the CO_2 injection (16000 Sm^{3}d) versus time. Fig. 5 presents the forecasted total amount of the exploited oil during the modeled process for three variants described above.

The calculation of the injection process shows that the injection of 23 mln Sm^3 CO_2 (during 8 years) without the breakthrough of CO_2 to the nearest well Jastrząbka Stara 8 is possible. The overall total oil production from this well up to 30 10^3 Sm^3 during 8 years is possible. The injection of CO_2 with the rate of 3 mln Sm^3/y will allow rising of reservoir pressure up to 20 bar, related to present state.

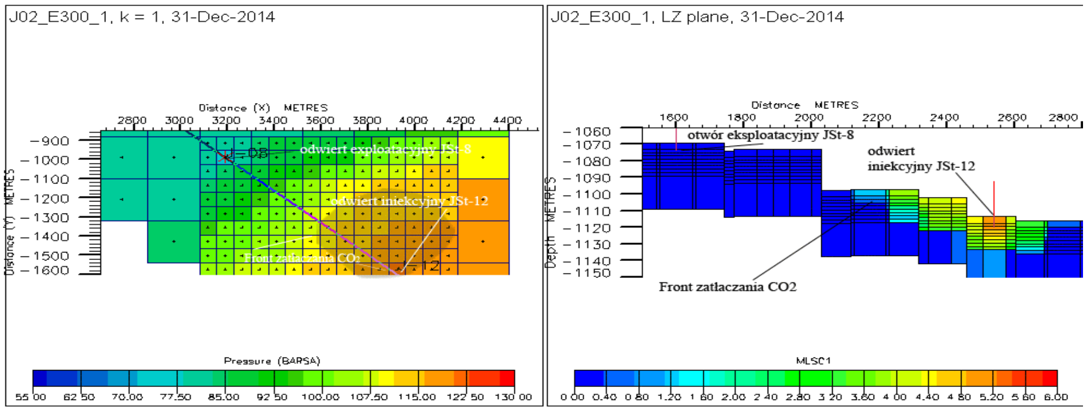

Fig. 3. Vertical cross-section of J-8 vs. J-12 showing the CO_2 molar concentration distribution (mol/m^3) at the end of 2014

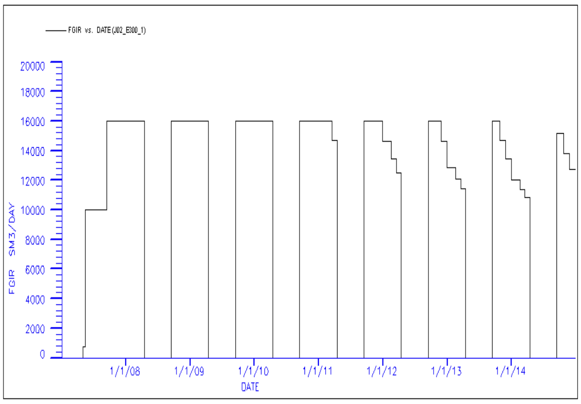

Fig. 4. Forecasted CO_2 injection efficiency during model process for the first injection variant.

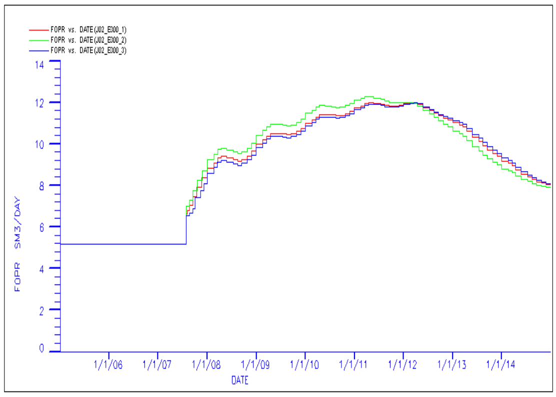

Fig. 5. Forecasted oil efficiency during the model process for three injection variants.

Example 2 – sequestration of CO_2 into the aquifer structure

The project of injection of CO_2 into the PONĘTÓW deep aquifer structure was prepared (Zawisza et al., 2005). The geological model of the aquifer structure was chosen using the work: Słupczyński, Papiernik, Migda, Zając (2004).

The performed model of the carbon dioxide injection into the water-bearing formation PONĘTÓW allows to formulate the following conclusions. The main problem was to create „gas bubbles" in the water-bearing structure, its enlargement and the determination of the peak-pressure in the layer. The simulation of the process allow to determine the target amount of injected CO_2 (20 10^3 Sm^3/d), it could be realized within 10 years of the injection without threats provided a confirmation of the structure tightness by other methods. In both variants it is possible to inject 127 mln Sm^3 of CO_2 (at the average pressure of 197 bars). The specification of the peak-pressure is the most important problem which should be sorted out in the case of a research continuation. In order to calculate it, it is necessary to produce a part of water from the structure in the upper part of the reservoir. Because of a high salinity of the reservoir water, the problem of water discharge should be taken into consideration.

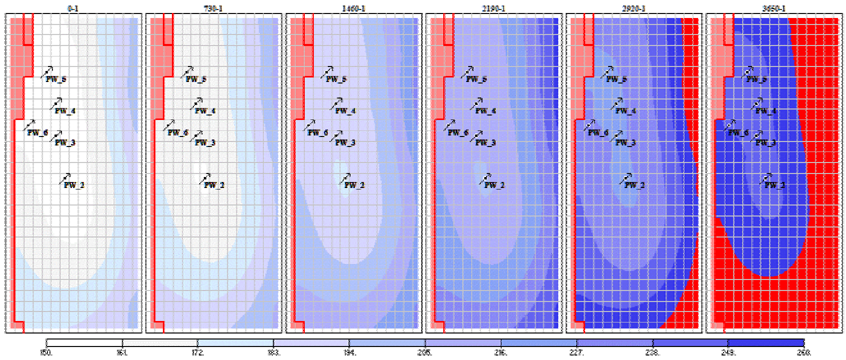

Fig. 6. Variables of the pressure during CO2 injection.

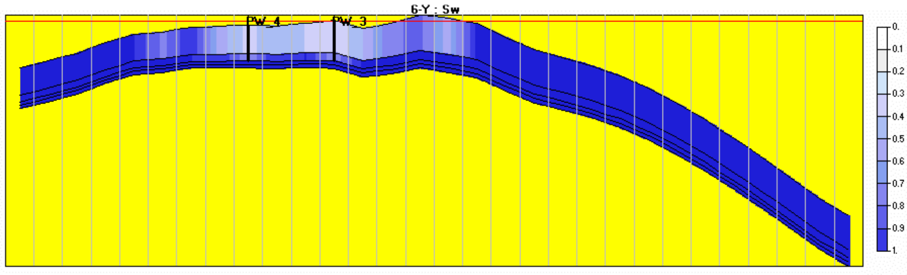

Fig. 7. Saturation distribution during CO2 injection – situation after 10 years of injecting.

Example 3 The experimental projects with the Enhanced Coal-Bed Methane (ECBM) in Silesia ("Recopol")

The RECOPOL project is an EC-funded research and demonstration project to investigate the technical and economic feasibility of storing CO_2 permanently in subsurface coal seams. The main aim of the project was to demonstrate that the CO_2 injection in coal under European conditions is feasible and that the CO_2 storage is a safe and permanent solution. This is the first field demonstration experiment of its kind in Europe. The development of the pilot site in the Upper Silesian Basin (Fig. 8) in Poland began in summer 2003.

One of the existing coalbed methane wells was cleaned up, repaired and put back into production (Fig. 9). A new injection well was drilled at 150 m from the production well. After the completion of the well with casing, cementing and perforations, the perforated zones were tested. A baseline cross borehole seismic survey was carried out for the monitoring purposes in September 2003. The activities in autumn 2003 included the finalizing of the injection facilities. The production started in the first half of June 2004, to establish a baseline production. First injection tests took place in the first week of July. Once the injection is stabilized, both injection and production is continuing. During the injection period, the process will be monitored directly and indirectly to assess any potential, although unlikely, leakage of CO_2 to the surface. Along with the field tests, an extensive laboratory program is carried out.

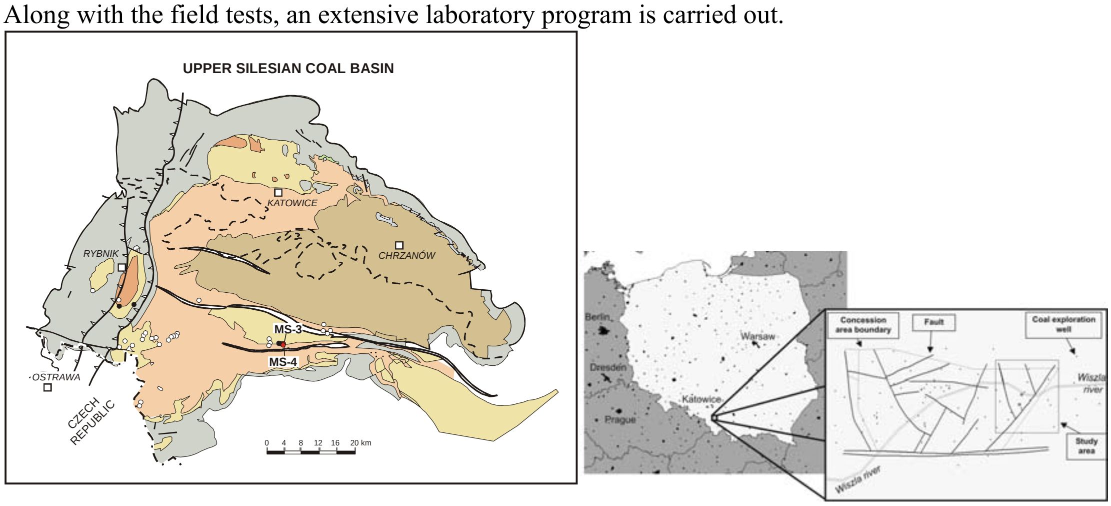

Fig. 8. Upper Silesian Coal Basin and the location of pilot wells (below).

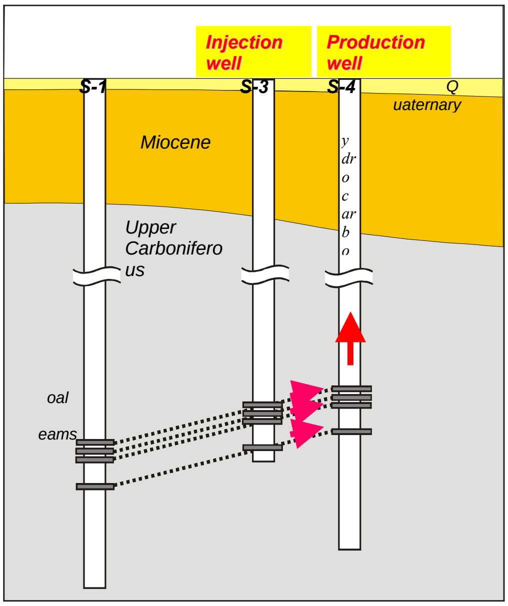

Fig. 9. Scheme of the completion of the pilot production-injection well of the Recopol project.

Conclusions

1. The calculation of the injection process show that the injection of 23 mln Sm^3 CO_2 (during 8 years) without the breakthrough of CO_2 to the nearest well Jastrząbka Stara 8 is possible. The overall total oil production from this well up to 30 10^3 Sm^3 during 8 years is possible. The injection of CO2 with the rate of 3 mln Sm3/y will allow rising of the reservoir pressure up to 20 bar, related to the present state. The sequestration of CO_2 during the oil production is possible, and results from this process may be useful during planning other EOR-CO_2 sequestration projects.
2. The simulation of the process of injection of CO_2 into the deep aquifer structure PONETÓW allow to determine the target amount of injected CO_2 (20 10^3 Sm^3/d), it could be realized within 10 years of the injection without threats provided a confirmation of the structure tightness by other methods. In both variants it is possible to inject 127 mln Sm^3 of CO_2 (at the average pressure of 197 bars).
3. The Recopol project, the first sequestration pilot onshore in Europe, inevitable to deal with all "soft" issues (permits, contracts, opposition, etc.) related to this kind of innovative projects. The lessons learned in this operation can possibly help to overtake the start-up barriers of a future CO_2 sequestration project in Europe.

Literature – References

[1] Słupczyński, Papiernik, Migda, Zając: Documentation of geologic structure of PONĘTÓW (In Polish), *2004.*
[2] IEA, 2002 – Solutions for the 21st Century. Zero Emissions Technologies for fossil Fuels. *Technology status report*
[3] DOE, 1999, U.S. Department of Energy, Working Paper on Carbon Sequestration Science and Technology
[4] Siemek, et al: Simulation of injection of CO2 to Jastrząbka reservoir - in: R. Tarkowski et al.: In situ researches of injection of CO2 in hydrocarbon reservoir – part I. (In Polish), *2006.*
[5] Pagnier, H., et al: Field Experiment of ECBM-CO_2 In The Upper Silesian Basin of Poland (Recopol) Proc. 7th Int. Conf. on Greenhouse Gas Control Technologies. Vol. 1 Peer-Reviewd Papers and Plenary Presentations, BC, September 5-9, 2004.
[6] Herzog, et al: What Future for Carbon Capture and Sequestration?, *Environmental Science and Technology, 35:7, pp 148 A–153 A, April 1, 2001.*
[7] Zawisza, L., et al.: Injection of waste into deep structures *(In Polish), report 2005.*