# Perspectives of Using Technologies for Geological Storage of Carbon Dioxide

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*Streszczenie*

*The aim of this paper is to show perspectives of using technologies for geological storage of carbon dioxide. Carbon dioxide gets into the atmosphere by increasing energy consumption, mainly by combustion of solid, liquid and gaseous fuels. Most of the emissions are produced from oil, coal and gas. Despite the fact, that carbon dioxide is one of the less harmful gases, it is necessary to consider the problem that may arise by increased production of gas, which can disrupt the balance of the ecosystem on the Earth.*

*Keywords: carbon dioxide, geological storage, parameters, perspective, geological site*

## Introduction

Human activity has an impact on the ecosystem of the planet. These activities seriously endangering the Earth. Carbon dioxide capture and storage has the potential to reduce $CO_2$ emissions from fossil fuel combustion (Holloway, 2007). A transition to a low-carbon economy can be facilitated by carbon dioxide capture and storage (Benson, 2006). One method of reducing the impact of carbon dioxide on the environment is the use of Carbon Dioxide Capture and Storage (CCS) technology. Carbon Dioxide Capture and Storage (CCS) technology has the potential to enable large reductions in global greenhouse gas emissions, but one of the unanswered questions about CCS is to what extent it will be accepted by the public (Singleton, 2009). The principle of this method is capture of carbon dioxide from large emission sources such as refineries, cement plants, steel mills and their subsequent transport and permanent storage in suitable geological formations. If CCS is implemented on the scale needed to make noticeable reductions in atmospheric $CO_2$, a billion metric tons or more must be sequestered annually a 250 fold increase over the amount sequestered today (Benson, 2008). There are concerns that public opinion and public's acceptance or rejection of this technology will likely affect the large-scale implementation of $CO_2$ geological storage (Bachu, 2008). The potential contrubution of this technology will be influenced by such as the cost relative to other options, the time that $CO_2$ will remain stored, the means of transport to storage sites, environmental concerns, and the acceptability of this approach (Metz, 2005).

## Determination of criteria for potential carbon dioxide storage sites

To determine the potential of the possible storages of carbon dioxide in depleted oil and gas deposit should be based on the availability of data collectors and surrounding locations. This is an important stage of determining the appropriate storage. Determination of geological site, to which will be carrying out geological sequestration of carbon dioxide, is gathering all possible data for a comprehensive assessment of the appropriate storage site and storage complex including overburden, the surrounding and the hydraulically connected areas.

Obtained data must contain at least the following characteristics of potential storage sites:

a) geological and geophysical parameters of storage deposit,
b) hydrogeology with respect to the existence of potable ground water,
c) geochemical parameters such as dissolution speed and mineralization rate, permeability, fracture pressure,
d) seismic parameters, especially the assessment of the risks caused by earthquake,
e) engineering parameters, including volumetric calculations - pores for carbon dioxide grouting, maximum storage capacity, temperature and pressure conditions, pressure volume behavior, cumulative grouting rate and time of grouting,
f) presence and condition of natural and artificial pathways, which could be used as leakage pathways,
g) geological structure of the area surrounding the storage complex, that may be affected by the storage of carbon dioxide,
h) distribution of the population in the region, where the storage site is situated,
i) proximity of scarce natural resources,

Tab. 1 Annual and daily production of carbon dioxide of interest manufacturing companies

Tab. 1 Roczna i dzienna produkcja dwutlenku węgla w zakładach produkcyjnych

| Producer of carbon dioxide | Production [t] | Production [$m^3$] | Production per day [$m^3.24\ h^{-1}$] |
|---|---|---|---|
| Power station Vojany | 570 000 | $293.10^6$ | $0{,}8.10^6$ |

Tab. 2 Deposit parameters of storage objects (part 1)

Tab. 2 Parametry obiektów składowania (część 1)

| Horizon parameters | 1st horizon | 2nd horizon | 3rd horizon |
|---|---|---|---|
| The initial deposit pressure in the reservoir $p_{POC}$ [MPa] | 6,5 | 6 | 7 |
| Volume of pores in deposit $\Omega$ [$m^3$] | $8.10^6$ | $10.10^6$ | $12.10^6$ |
| Coefficient of permeability [$pm^2$] | 0,4 | 0,45 | 0,4 |
| Coefficient of porosity m [-] | 0,2 | 0,18 | 0,2 |
| Coefficient of dynamic viscosity $p_D$ [$MPa.s^{-1}$] | 0,012 | 0,012 | 0,012 |

j) possible interactions with other activities (exploration, extraction, storage of hydrocarbons, geothermal use of aquifers).

Choosing a suitable location for geological sequestration of carbon dioxide is made on the base of the structural maps assessment, bearing and geological characteristics of individual sites. Qualifying conditions for the selection of suitable sites for storing of carbon dioxide are:

- The depth of the deposit
- Tectonics
- Capacity of the deposit
- The number of opening wells of the deposit.

**Theoretical aspects of carbon dioxide storage**

Storage of carbon dioxide depends on its mechanical properties. It is assumed, that the horizon for the storage of carbon dioxide lies at the depth of 800 m and more, the temperature and pressure at that depth changes the phase of carbon dioxide. Its specific density is very similar to the value of supercritical liquid. This transition to a supercritical state is given by the pressure of 7.38 MPa and a temperature of 31.1°C. In this supercritical state, carbon dioxide occupies less space in the pores as in its gas phase. The density of carbon dioxide depends on the depth and increases at the depth of 600 to 800 m. At the depth of 1000 m reaches its maximum. In the terms of economic reasons, lower limit of carbon storage is acceptable to a depth of 3000 m. In normal conditions, when the temperature is 25°C and a pressure is 0.1 MPa, the carbon dioxide density is 1.977 $kg.m^{-3}$. It means, that one ton of carbon dioxide takes up a volume of 526 $m^3$. At a depth of 1000 m, the temperature and pressure conditions characteristic of this depth (35°C, 10 MPa), one ton of carbon dioxide takes an area of 1.5 $m^3$ and a density value of carbon dioxide is 650 $kg.m^{-3}$. For an effective shifting of carbon dioxide into the deposit, its density should be in the range of 600 to 800 $kg.m^{-3}$, temperature of 30°C and a pressure of 8 MPa.

**Propose of storage technologies**

Use of hydrocarbon deposits to store carbon dioxide also entails the advantage of increasing the recovery rate from primary products by increasing the pressure of pushing carbon dioxide. This can reduce the economic inefficiency.

**Source of carbon dioxide project**

As a source of carbon dioxide production, we have designed Vojany (power station in Slovak Republic). It produces annually 570,000 tons of carbon dioxide, which represents a volume of 293,106 cubic meters. The operation of the power station should be completed in 2016. There are plans to decommission and dispose of five blocks. Consequently, it is planned to build three new units with CCS technology. The project called NICA will capture and store carbon dioxide from power station.

**Calculation of storage capacity**

This natural gas deposit is mined and we have available data. These data can be used for calculation of possible storage capacity of the objects.

Within a deposit are three horizons, which have good collector properties. This object is located a few kilometers from the source of carbon dioxide.

*The maximum volume that can be pushed into the storage QA:*

Tab. 3 Deposit parameters of storage objects (part 2)

Tab. 3 Parametry obiektów składowania (część 2)

| **Horizon parameters** | **1st horizon** | **2nd horizon** | **3rd horizon** |
|---|---|---|---|
| Thickness of the layer h [m] | 12 | 13 | 14 |
| Radius of probe (full opening of the deposit) R [m] | 0,15 | 0,15 | 0,15 |
| Number of probes, which are used for pushing carbon dioxide n [piece] | 6 | 6 | 5 |
| Permanent rate of injection N(t) [$m^3$.24 $h^{-1}$] | $0{,}4.10^6$ | $0{,}5.10^6$ | $0{,}4.10^6$ |
| Maximum allowable deposit pressure $p_{MAX}$ [MPa] | 9 | 9 | 10 |
| Depth of the probe L [m] | 1410 | 1470 | 1540 |
| Inner diameter of the upstream column d [m] | 0,139 | 1,32 | 0,139 |
| Coefficient of hydraulic resistance pipe X | 0,02 | 0,02 | 0,02 |
| Relative density of gas A | 1,52 | 1,52 | 1,52 |
| Pressure of the compressor in the suction collector $p_B$ [MPa] | 2 | 2 | 2 |
| Temperature of the compressor in the suction collector $t_B$ [°C] $T_B$ [K] | 20, 293 | 20,293 | 20,293 |
| Compressibility factor z [-] | 1 | 1 | 1 |
| Deployment of probes open deposit surface **[-]** | uniform | uniform | uniform |
| Coefficient of filter resistance B [-] | 0 | 0 | 0 |

$$\mathrm{Q_A} = \Omega.(p_{LMAX} - p_{LPOC}).g \qquad [\mathrm{m}^3]\ (1)$$

$Q_A$ – maximum volume that can be pushed into the storage [$m^3$]
Ω – volume of pores in deposit [$m^3$]
$p_{L\,MAX}$ – maximum allowable deposit pressure [MPa]
$p_{L\,POC}$ – initial deposit pressure in the reservoir [MPa]
g – gravity acceleration [$m.s^{-2}$]

*Total volume of the horizon storage QC:*

$$\mathrm{Q_C} = \Omega.p_{LPOC}.\mathrm{g} + \mathrm{Q_A} \qquad [\mathrm{m}^3]\ (2)$$

$Q_C$ – total volume of the horizon storage [$m^3$]
Ω – volume of pores in deposit [$m^3$]
$p_{L\,POC}$ – initial deposit pressure in the reservoir [MPa]
$Q_A$ – maximum volume that can be pushed into the storage [MPa]

*The ratio of active volume and hassock x:*

$$x = \frac{\mathrm{Q_A}}{(\Omega.\mathrm{p_{LPOC}}.g)} \qquad (3)$$

$Q_A$ – maximum volume that can be pushed into the [MPa]
Ω – volume of pores in deposit [$m^3$]
$p_{L\,POC}$ – initial deposit pressure in the reservoir [MPa]
$Q_C$ – total volume of the horizon storage [$m^3$]

*Pressure at the bottom of the probe, at the end of the compression, $p_h$=$p_{max}$, R=$R_k$, Ɛ1=0, Ɛ2=0:*

$$\mathrm{R_k} = \sqrt{\frac{\Omega}{(\pi.\mathrm{h.m.n})}} \qquad [\mathrm{m}]\ (4)$$

$R_k$ – horizon of the contact of water – gas [m]
h – thickness of the layer [m]
m – coefficient of porosity [-]
n – number of probes, which are used for pushing carbon dioxide [pieces]

*Pressure at the bottom of the probe at the end of pushing pLprobe:*

$$\mathrm{p_{Lprobe}} = \sqrt{p^2{}_{\mathrm{max}} + \frac{N(t)\ln\frac{R_k}{R_C}}{n.A_p}} \qquad [\mathrm{MPa}]\ (5)$$

$p_{Lprobe}$ – pressure at the bottom of the probe at the end of pushing [MPa]
$p_{max}$ – maximum allowable deposit pressure [MPa]
N(t) – permanent rate of injection [$m^3$.24 $h^{-1}$]
$R_k$ – horizon of the contact of water – gas [m]
$R_c$ – semi-diameter of the probe [m]
n – number of probes, which are used for pushing carbon dioxide [piece]
$A_p$ – coefficient [$m^3$.24 $h^{-1}$]
ln – natural logarithm [-]

Tab. 4 The maximum volume that can be pushed into the storage

Tab. 4 Maksymalna objętość, która może być skierowana do składowania

| | |
|---|---|
| Calculation for the 1st horizon storage | $Q_A = 8.10^6.(9-6{,}5).9{,}81 = 196.10^6$ [m³] |
| Calculation for the 2nd horizon storage | $Q_A = 10.10^6.(9-6).9{,}81 = 294.10^6$ [m³] |
| Calculation for the 3rd horizon storage | $Q_A = 12.10^6.(10-7).9{,}81 = 353.10^6$ [m³] |

Tab. 5 Total volume of the horizon storage QC

Tab. 5 Całkowita perspektywiczna objętość składowania QC

| | |
|---|---|
| Calculation for the 1st horizon storage | $Q_C = 8.10^6.6{,}5.9{,}81 + 196.10^6 = 706.10^6$ [m³] |
| Calculation for the 2nd horizon storage | $Q_C = 10.10^6.6.9{,}81 + 294.10^6 = 883.10^6$ [m³] |
| Calculation for the 3rd horizon storage | $Q_C = 12.10^6.7.9{,}81 + 353.10^6 = 1177.10^6$ [m³] |

Tab. 6 The ratio of active volume and hassock x

Tab. 6 Stosunek objętości aktywnej i podłoża x

| | |
|---|---|
| Calculation for the 1st horizon storage | $x = \frac{196.10^6}{\left(8.10^6.6{,}5.9{,}81\right)} = 0{,}38$ |
| Calculation for the 2nd horizon storage | $x = \frac{294.10^6}{10.10^6.6.g} = 0{,}49$ |
| Calculation for the 3rd horizon storage | $x = \frac{353.10^6}{12.10^6.7.9{,}81} = 0{,}42$ |

Tab. 7 Pressure at the bottom of the probe, at the end of the compression

Tab. 7 Ciśnienie na spodzie próby, pod koniec kompresji

| | |
|---|---|
| Calculation for the 1st horizon storage | $R_k = \sqrt{\frac{8.10^6}{\left(3{,}14.12.0{,}2.6\right)}} = 420$ [m] |
| Calculation for the 2nd horizon storage | $R_k = \sqrt{\frac{10.10^6}{\left(3{,}14.13.0{,}18.6\right)}} = 476$ [m] |
| Calculation for the 3rd horizon storage | $R_k = \sqrt{\frac{12.10^6}{\left(3{,}14.14.0{,}2.5\right)}} = 522$ [m] |

Tab.8 Pressure at the bottom of the probe at the end of pushing

Tab. 8 Ciśnienie na spodzie próby, pod koniec wtłaczania

| | |
|---|---|
| Calculation for the 1st horizon storage | $\mathrm{p}_{\mathrm{Lprobe}} = \sqrt{\left(9.10^{6}\right)^{2} + \frac{4,629\ln\frac{420}{0,15}}{6.0,118}} = \sqrt{\left(8,1\right)^{13} + \frac{36,74}{0,708}} = \sqrt{\left(8,1\right)^{13} + 51,89} = 9,0$ [MPa] |
| Calculation for the 2nd horizon storage | $\mathrm{p}_{\mathrm{Lprobe}} = \sqrt{\left(9.10^{6}\right)^{2} + \frac{5,787\ln\frac{476}{0,15}}{6.0,144}} = \sqrt{\left(8,1\right)^{13} + \frac{46,657}{0,864}} = \sqrt{\left(8,1\right)^{13} + 54,00} = 9$ [MPa] |
| Calculation for the 3rd horizon storage | $\mathrm{p}_{\mathrm{Lprobe}} = \sqrt{\left(10.10^{6}\right)^{2} + \frac{4,629\ln\frac{522}{0,15}}{5.0,138}} = \sqrt{\left(1.10\right)^{14} + \frac{37,74}{0,69}} = \sqrt{\left(1.10\right)^{14} + 54,69} = 10$<br>[MPa] |

*The pressure at the orifice of the discharge probe at the end of the period of pushing p uprobe:*

$$\mathrm{p}_{\mathrm{uprobe}} = \sqrt{p^{2}Lprobe.e^{-2s} + \frac{1,377.10^{-2}.z^{2}.\tilde{T}^{2}.\lambda.Q^{2}}{d^{5}}.(e^{-2s}-1)}$$

[MPa] (6)

**Propose of storage technology of carbon dioxide**

We used available information of the annual production of carbon dioxide from power station located in the vicinity of the repository for the proposed technology. We calculated the annual volume of produced carbon dioxide in cubic meters from the annual production in tonne and then daily amount. We used this data for specification of compressor and modeling of the individual objects of repository.

**Conclusion**

Carbon storage technologies offer new possibilities for reducing human impact on global climate change. Although carbon dioxide is not as dangerous as toxic gases, its discharge into the atmosphere causes the greenhouse effect of global warming. It is necessary to reduce the emission of greenhouse gases into the atmosphere to mitigate the negative climate change and look for ways and possibilities for their storage. Extracted hydrocarbon deposits appear as suitable storage sites of separated carbon dioxide. The disadvantage is, that only in a few cases place of production activities or large emitters of carbon dioxide geographically coincides with the location of suitable repository. This article considered Eastern Slovakia as a geographically suitable position. Section of current technologies of collection centers can be used for the operation of the storage of carbon dioxide. The biggest advantage is the connection with the distribution network of natural gas. This benefit was reflected in the choice of the compressor. The availability of natural gas, either from a distribution network or from the extraction of gas during the operation of the repository, was decisive for the choice of a combustion gas turbine as a drive for the compressor.

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### *Perspektywy zastosowania technologii składowania dwutlenku węgla w formacjach geologicznych*

*Celem artykułu jest przedstawienie perspektyw zastosowania technologii składowania dwutlenku węgla w formacjach geologicznych. Zwiększenie emisji dwutlenku węgla jest spowodowane przedewszystkim rosnącym zużyciem energii, produkowanej głównie w procesach spalania paliw stałych, ciekłych i gazowych. Większość emisji powstaje ze spalania ropy naftowej, węgla oraz gazu ziemnego. Zwiększona produkcja dwutlenku węgla zakłócić bilans ekosystemu Ziemi.*

*Słowa kluczowe: dwutlenek węgla, składowanie w formacjach geologicznych, stanowisko geologiczne*