Characterisation of European CO_2 storage

Integrity analysis of all existing wells

S. Nagy (AGH), L. Klimkowski (AGH), K. Polański (AGH),
T. Włodek (AGH), M. Mazurowski (PGNIG)

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Well integrity / Well barrier

Application of technical, operational and organizational solutions to reduce risk of uncontroled release of formation fluids through out the life cycle of a well.

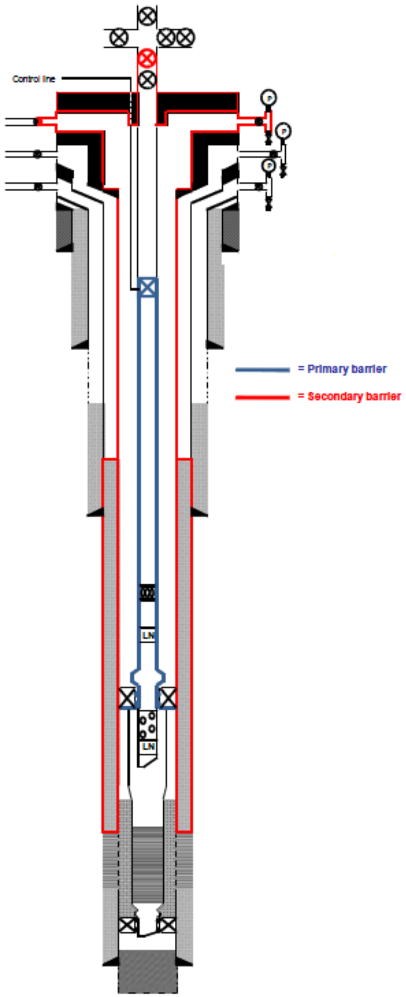
Envelope of one or several dependent barrier elements preventing fluids or gases from flowing unintentionally from the formation into other formation or to surface.

Wellbore integrity issues

- one of the most important elements of ensuring the safe long-term geological storage of CO_2,

- divide into two types:
  1. improper completion and abandonment of the wells (depleted oil and gas reservoirs)
  2. long-term stability of wellbore materials in a CO_2-rich environment (cement, steel)

Well barriers



D'Alesio et al. 2010

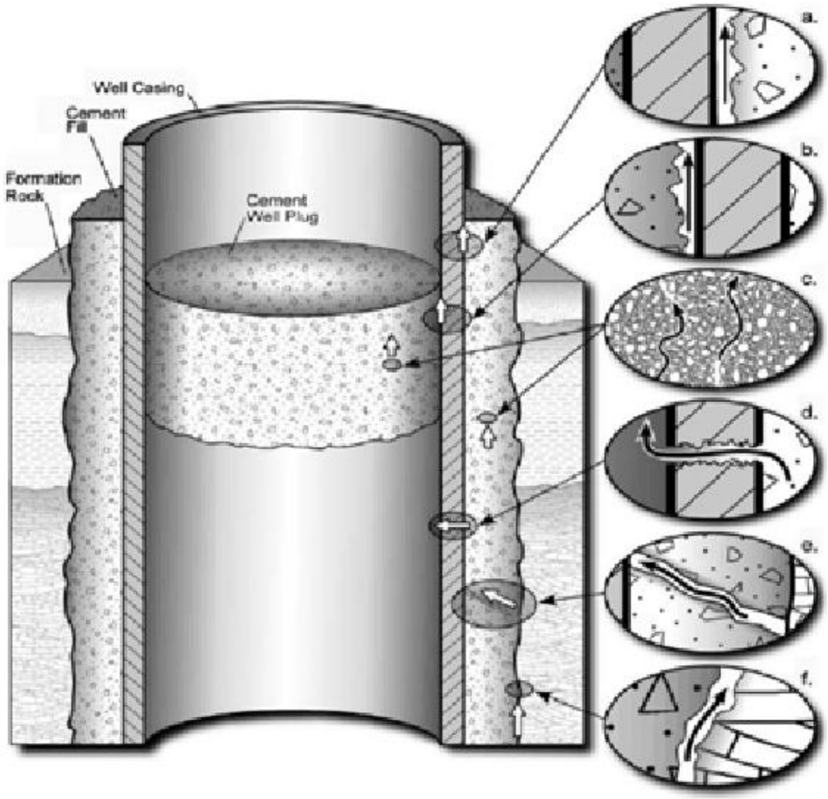
Primary barrier:

- injection tubing
- packer
- safety valve

Seconadry barrier:

- casing
- cement outside the casing
- wellhead valves

Potential wellbore leakage pathways



Celia et al. 2004

a. between casing and cement
b. between plug and casing
c. through the cement pore space
d. through the casing
e. through fractures in cement
f. between cement and formation

also

- through completion equipment (packers, plugs, safety valves)
- through tubing hangers

Mechanical integrity methods

- **Internal mechanical integrity:**

– pressurizing inner annulus

- **External mechanical integrity:**
  - **cement evaluation (acoustic cement logs to determine cement tops and the quality of the casing-cement and cement-rock bonds**
  - **evaluation of casing thickness**
  - **tree and wellhead integrity (valves)**

Well integrity evaluation

1. **Data colection – gathering all available data to characterize the well and its surrounding:**
   - **well completion design documents**
   - **drilling and cementing documents**
   - **cement and corrosion logs / cement parameters**
   - **production history**
   - **workover / abandonment reports**
   - **fluid composition/saturation in formations intersected**
   - **properties of all formations intersected**

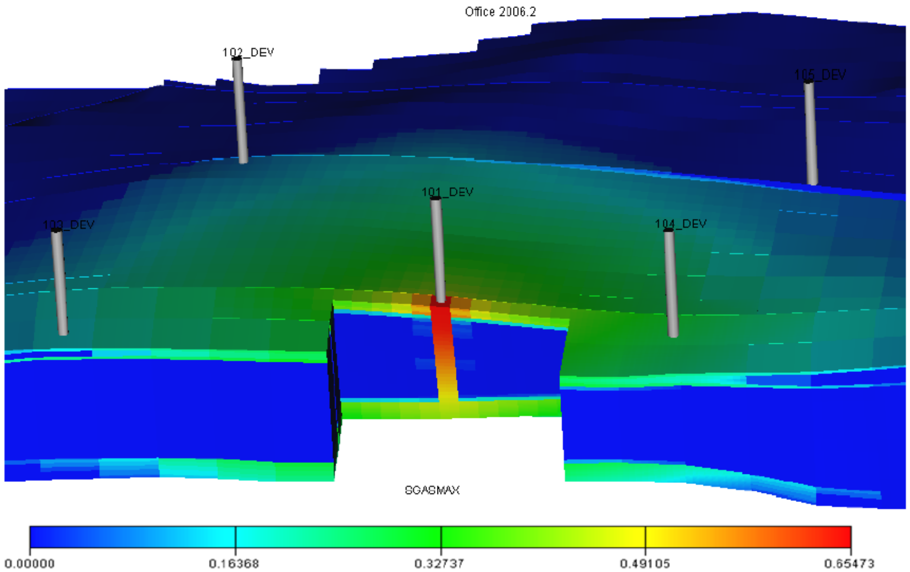
2. Static model of the well in geological context:

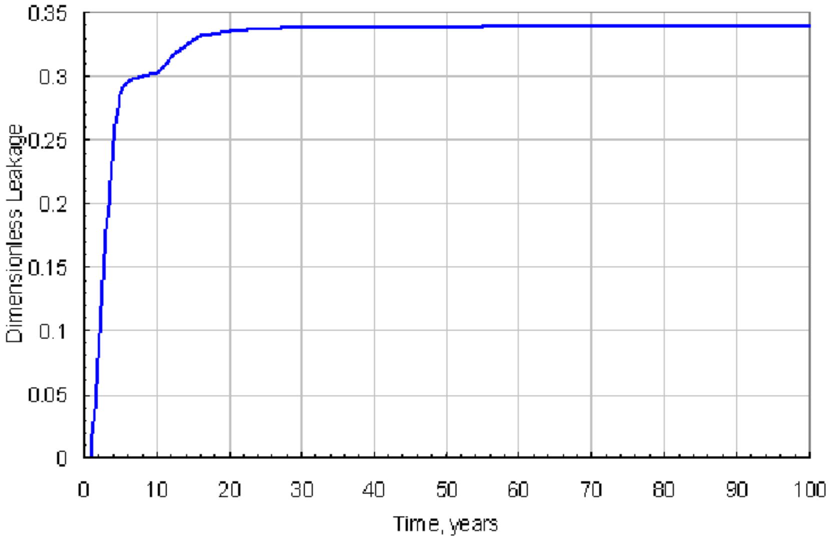
- **cement sheath described as a porous, permeable media saturated with brine (porosities and permeabilities modified to account for the degradation effects)**

Well integrity evaluation

3. Dynamic model

- predict the leakage pathways
- compute CO_2 leakage rates at any point of interest (shallow aquifer, surface…)





Uncertainties

Uncertainties often have to be considered on parameters such as:

- **geometrical and mechanical properties of static model**
- **degradation mechanisms kinetics**
- **initial and boundary conditions**

Each scenario will thus be a combination of a specific set of parameters describing the static and dynamic modelling within the range of uncertainties.

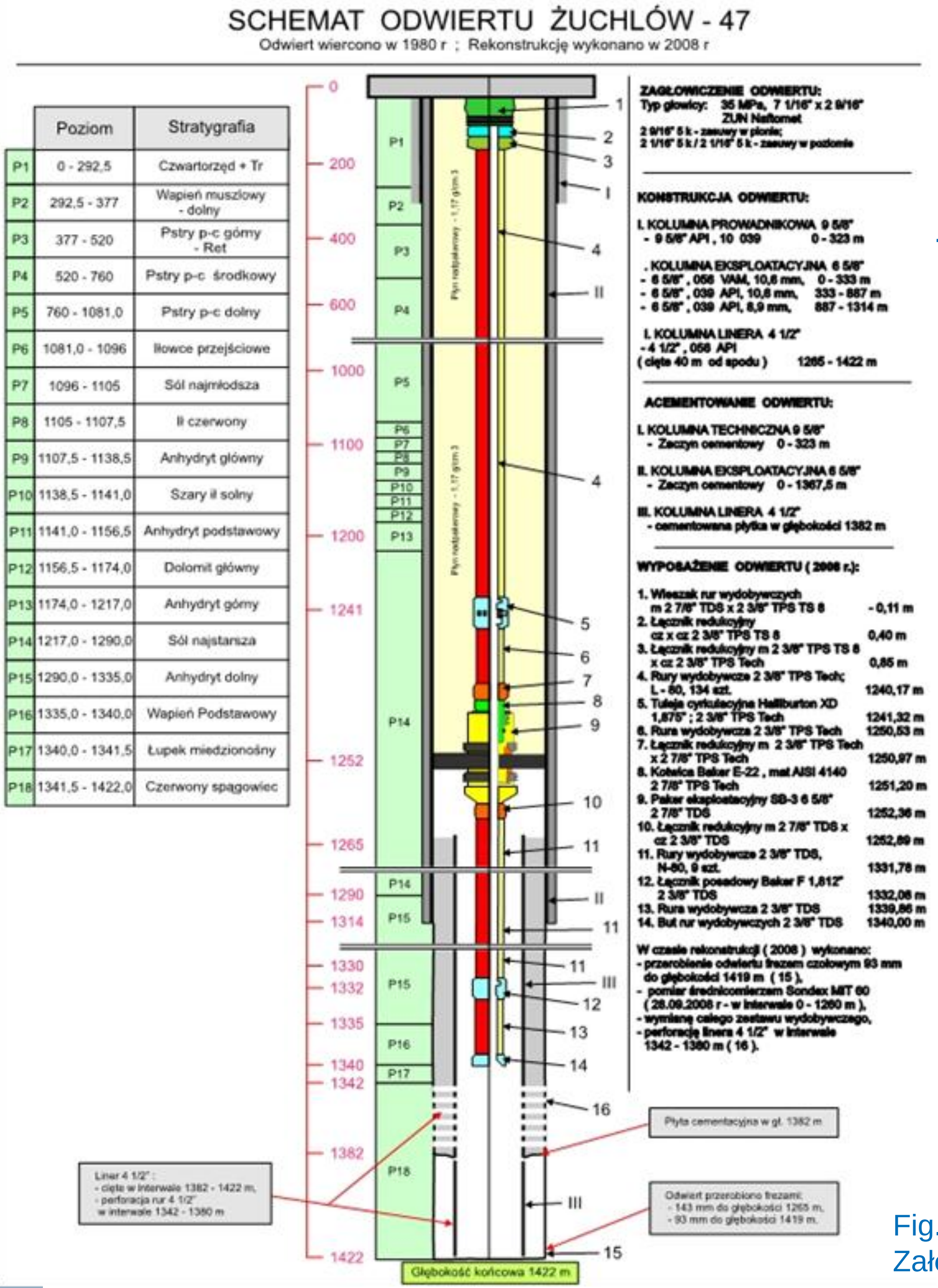
Objectives/Challenges

- **Possible leakage through existing wells recognized as the most probable pathway for CO_2 leakage**

- **Identification of potential risks**
  - **Evaluation of the state of the Well**
  - **Analysis of well integrity**

- **Challenges**
  - **Number of wells**
  - **Availability of proper data**
  - **Well accessibility**

Review of existing data



The understanding of the existing and abandoned wells is necessary to have general view on potential safety problems during storage processes.

Fig. 2 Wellbore construction example from the Żuchlów - Załęcze Field – Well Żuchlów - 47.

Review of existing data – MIT Report

- MIT tools allow to detect very small changes to the internal surface condition of casing.
- A total of 115 joints were analyzed, of which none have possible holes.
- The field inspection has been performed aiming to check corrosion progress in the selected wells in the Żuchlów–Załęcze.
- Because of different types of corrosion, the analysis has been focused on the integrity of elements of casing.
- The most restricted joints are:

  Projections to 3.91 mm (in coupling) in Joint 25;

  Projections to 2.34 mm in Joint 111.

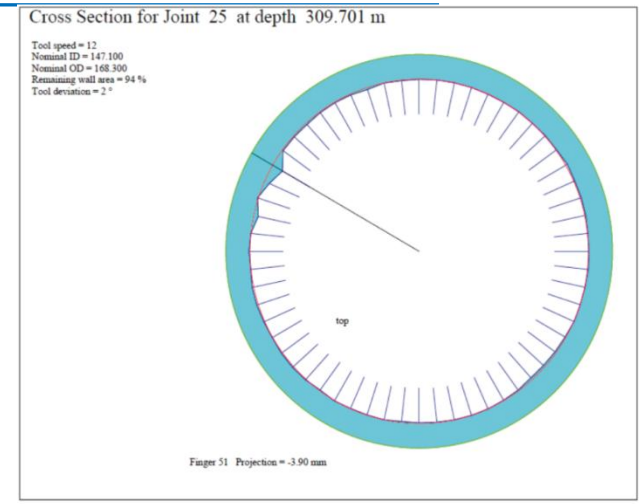


Fig. 3 Cross section for selected Joint.

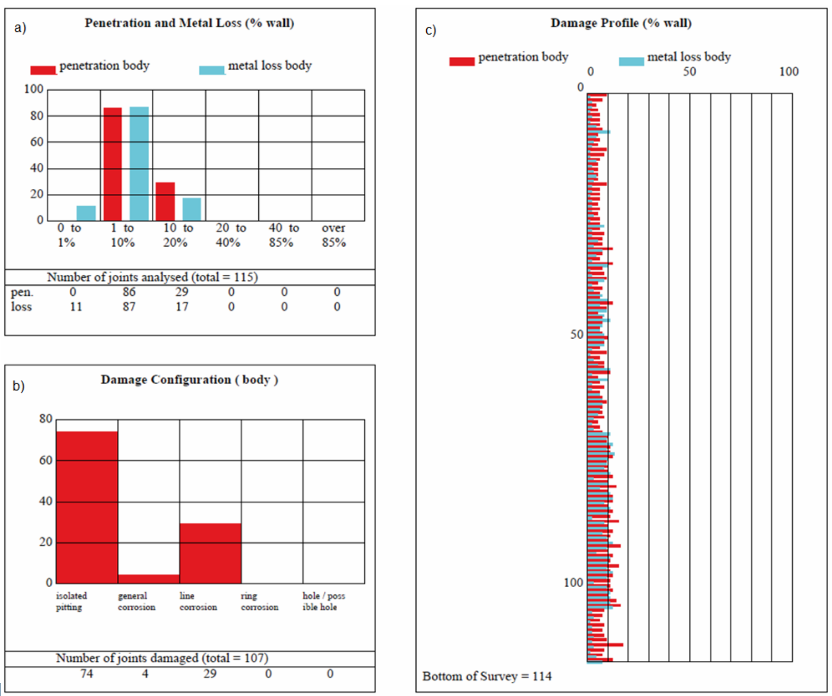


Fig.4 b) classifies pipe body damage for a total of 107 pipes with detected corrosion. It should be noted that prevailing (69%) is isolated pitting type of corrosion.

Fig.4 c) presents distribution of maximum damage of whole measured pipes with comparison to metal loss.

Fig. 4 Histograms presenting state of the casing (pipe body):

a) penetration and metal loss (% wall), b) damage profile (%wall), c) damage configuration (body).

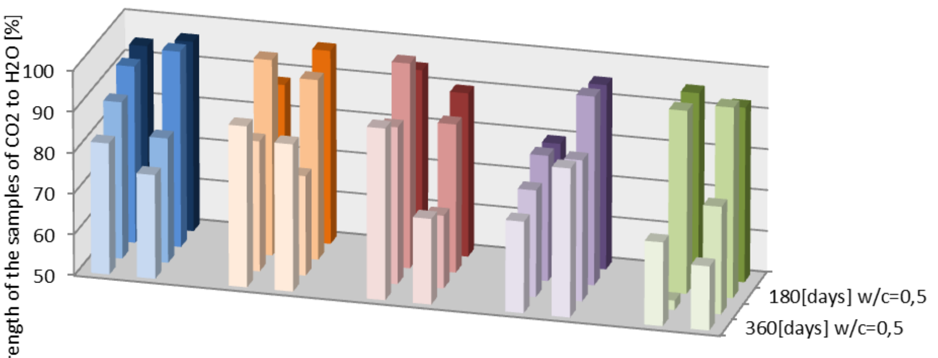
Review of existing data - Laboratory tests

Data of cementation operation in Polish industry have been collected, described and verified, with focus on the 1970-1990 year of activity. The laboratory work aimed to estimate potential rate of corrosion of cement (samples taken from the area of Żuchlów field).

Fig. 5 Corroded cement

The test samples were determined using Michaelis apparatus (bending strength) and a hydraulic press (compression strength). The study involved a sample stored 6 and 12 months in the water and in the CO_2 atmosphere.

Fig. 6 Pressure vessel



	KUJ 42,5R ben. [%]	KUJ 42,5R comp. [%]	MAŁ 42,5 ben. [%]	MAŁ 42,5 comp. [%]	KUJ HSR ben. [%]	KUJ HSR comp. [%]	G (API) ben. [%]	G (API) comp. [%]	REJ HSR ben. [%]	REJ HSR comp. [%]
360[days] w/c=0,5	82	75	89	86	92	71	72	86	70	66
360[days] w/c=0,6	88	80	82	74	88	68	76	84	52	76
180[days] w/c=0,5	93	98	98	94	100	86	81	96	95	96
180[days] w/c=0,6	94	96	88	97	95	90	80	95	95	93

Fig. 7 Summary of results of laboratory tests

- The results shows the drop resistance of all tested samples characterized by an insignificant value after 180 days of storage.
- The lowest value, (52% strength of the value for H_2O), is reached for Rejowiec HSR cement in compare bending strength of samples from CO2 to H_2O for 360 days
- The highest value is (92 % of the value for H_2O) for Kujawy HSR cement in compare bending strength of samples from CO2 to H_2O for 360 days test.

Conclusions from cement quality laboratory tests

- Drop resistance to all tested sealing slurries characterized by an insignificant value for the 180 days of storage time and the values in compare bending strength of samples from CO_2 to H_2O for 360 days test: the lowest strength (52% of the value for H_2O) for Rejowiec HSR to the highest strength (92% of the value for H_2O) for Kujawy HSR).

- The impact of water - cement ratio to reduce the strength of the test samples is specific of the cement types.

- Cement CEM I 42.5 Małogoszcz, Drilling cement HSR Kujawa and Drilling cement class G to the API are characterized by smaller decreases in strength at lower coefficient water – cement (the water content in the cement slurry).
- Rejowiec HSR Drilling Cement is one of the five tested cements that are the least resistant to the corrosive environment of CO_2 (52% of strength decrease after 360 days in a CO_2 environement). Therefore it is not to be recommended to use this cement in a context of CO_2 storage.

- The best cement in terms of mechanical strength resistance in an atmosphere of CO_2 is the Portland Cement 42.5R Kujawy.

- The most favourable cement from all tested cements is the Portland Cement 42.5R Kujawy which showed smaller decreases in strength for higher water - cement rates and high mechanical strength.one to be used in CO_2 atmosphere but the final decision should be made after having analysed data from well logs, ERT and CBL.

Well integrity monitoring after workover - recommendations

Soil sampling

Soil sampling and geochemical analysis are the simplest solution to detect CO_2 leaks at surface.

Tracers with different isotopic composition can be added to CO_2 injection stream of each well to allow identification of any possible unplanned CO_2 migration outside the store.

Pressure and temperature monitoring

Downhole pressure and temperature measurements are used to validate and calibrate static and dynamic modelling developed to track the CO_2 plume migration in the reservoir.

Analysis of leakage scenarios - numerical model and results of the simulations CO_2 leak from wells

- The static model was associated with average petrophysical data according to WP5
- Cement outside the casing is represented by three very fine blocks along the radial direction: a first one, with a 0.1 mm width, represents the micro-annulus between the casing and cement and the two other ones represent the cement matrix.
- Cement permeability and porosity are assumed and equal to 20 mD and 30%, respectively.
- Permeability of the micro-annulus was changed in simulation to represent different conditions of cement bonding.

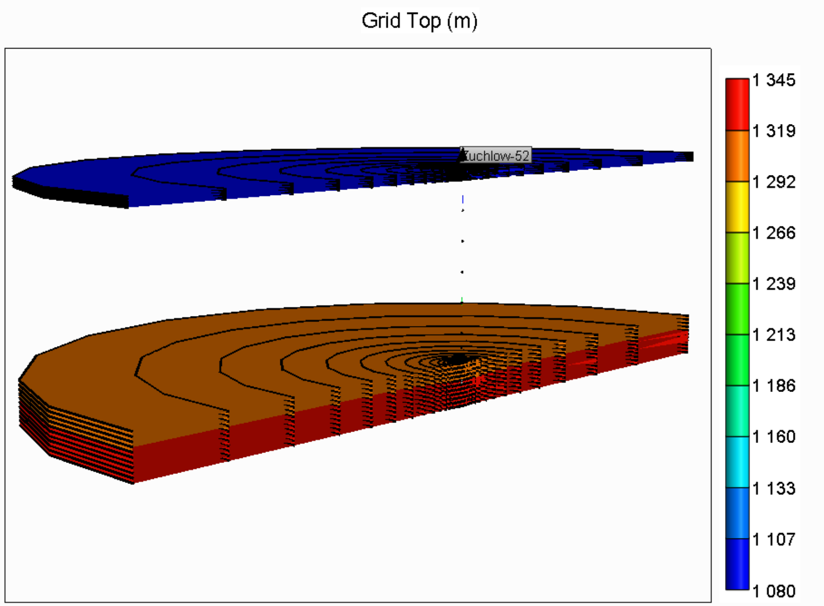


Fig. 8 3D cross-section view of the static model of representative well Żuchlów-52, its surrounding and secondary reservoir (the worst case of well integrity example based upon Żuchlów 52 well)

- During this time, CO2 migrates through the water-saturated cement up to the secondary reservoir in shallower carbonate layers (Ca2).
- The mass of the CO2 leakage and its saturation in the top layer of the secondary reservoir are recorded in simulation output files.
- The amounts of CO2 leakage in each simulation run are the main outcomes to be used for the well integrity-related risk analysis.

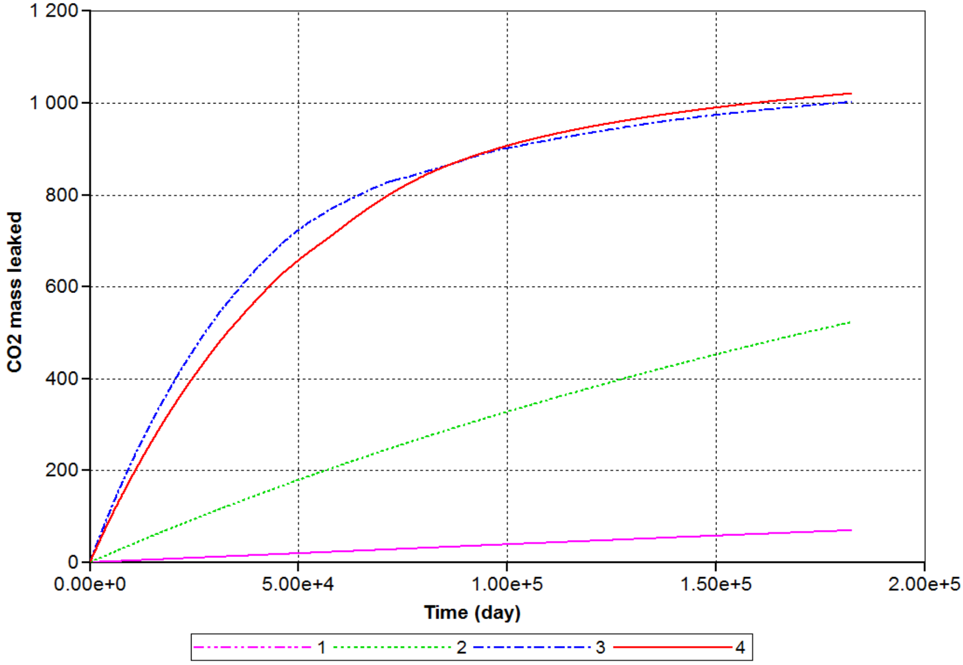
Analysis of leakage scenarios

Table 2 Simulation scenarios characteristics and results

Scenario number	Micro-annulus permeability [mD]	Cement permeability [mD]	Mass of leaking CO_2 recorded in the secondary reservoir [tonne]
1	10	0.02	70.0
2	100	0.02	523.1
3	100	100	1002.0
4	0 (no micro-annulus)	100	1020.7

- CO2 leakage in case of **good cement quality and not complete cement bonding -** 140 kg per year, resulting with total leakage of 70.0 tonne for a period of 500 years.
- **Good cement quality** but **low cement bonding quality** results - leakage rate up to 1,0 tonne of CO2 per year, with total amount over 500 tonnes in analyzed period.
- In case of **high permeability of cement itself & low cement quality,** CO2 leakage is the highest (more than 1000 tonnes) and permeability of the microannulus is of less influence on the overall leakage.
- Overall amount of CO2 leaked through one leaking well is relatively low taking into consideration the amount of injected CO2 and long time scale of the process.

Fig. 9 Masse of CO2 mass leaking from the storage reservoir to the secondary reservoir after a 500 years period for different simulation scenarios.



Analysis of leakage scenarios - Conclusions from simulations

- Performed simulation based investigation gives an overall view of the possible CO_2 leakage through the old abandoned wells in Załęcze & Żuchlów site.

- With pre-assumed storage pressure cement and cement bond quality are the most significant parameters from the well integrity point of view.

- Taking into consideration that relatively low amount of CO_2 leaked even in the worst case scenarios, identifying and proper abandonment of the most risky wells can significantly increase the safety of CO_2 storage.

- Detailed analysis of the cement itself and cement bond quality is necessary in this case for further well integrity analysis and its influence on storage safety.

Monitoring strategies

Table 3 summarizes potential in well monitoring technologies and well integrity storage assurance.

Additional corrosion tests should be performed on the basis of field tests to determine the uniform corrosion, pitting and stress using selected materials.

Cement bond logs should not be relied on for a quantitative evaluation of zonal isolation or hydraulic integrity.

Table 3 Well Logging Technologies for Wellbore Integrity check

Monitoring Technique	*Description, Benefits and Challenges*
Injection Well Logging	*Description: Wellbore measurement using a rock parameter, such as resistivity or temperature, to monitor fluid composition in wellbore.*
	Benefits: Easily deployed technology and very useful for wellbore leakage.
	Challenges: Area of investigation limited to immediate wellbore. Sensitivity of tool to fluid change.
Electrical Resistance Tomography (ERT)	*Description: Use of vertical arrays of electrodes in two or more wells to monitor CO2 as a result of changes in layer resistivity.*
	Benefits: Potential high resolution technique to monitor CO2 movement between wells.
	Challenges: Immature technology for monitoring of CO2 movement. Processes such as mass balance and dissolution/mineral trapping difficult to interpret. Poor resolution and limited testing in GS applications.
Optical Logging	*Description: Device equipped with optical imaging tools is lowered down the length of the wellbore to provide detailed digital images of the well casing.*
	Benefits: Simple and cheap technology that provides qualitative well integrity verification at depth.
	Challenges: Does not provide information beyond what is visible inside the well casing.
Cement Bond Log	*Description: Implement sonic attenuation and travel time to determine whether casing is cemented or free. The more cement which is bonded to casing, the greater will be the attenuation of sounds transmitted along the casing. Used to evaluate the integrity of the casing cement and assessing the possibility of flow outside of casing.*
	Benefits: Evaluation of quality of engineered well system prior to leakage, allows for proactive remediation of engineered system. Indicates top of cement, free pipe, and gives an indication of well cemented pipe. Authorized as an MIT tool for the demonstration of external integrity of injection wells.

Risk assessment - Conclusions

- Casing inspection of the well Żuchlów-47 were performed using MIT for checking downhole tubulars corrosion symptoms. A total of 115 joints were analysed, among which none have possible holes.

- Laboratory work performed by AGH show that CO2 corrosive atmosphere reduces the strength of hardened sealing slurries. Drop resistance to all tested sealing slurries characterized by insignificant value for the 180 days of storage time and the values of 50% to 90% of bending strength value measured for cement kept in H2O for 360 days. The impact of the water - cement ratio on the reduction of the strength of the tested samples is specific to the types of cement.

- A programme of well integrity tests after working over the well as well as a number of tasks dedicated to risk assessment have been prepared.

- Numerical simulations give an overall view of the possible CO2 leakage through the old abandoned wells in Załęcze & Żuchlów site.

- During the simulation time that covers a 500 years period after CO2 injection, CO2 migrates through the water-saturated cement up to the secondary reservoir in shallower carbonate (Ca2) layers. Four simulations were performed to investigate the effect of different micro-annulus and cement permeability on CO2 leakage.

- The need for mitigation or remediation is determined by national authorities and by the EU directive. Mitigation or remediation may begin as soon as CO_2 is known, or suspected, to migrate out of the formation.

Lessons learnt/recommendation

- Possible leakage through existing wells recognized as a major risk/issue
- Need for well integrity analysis that include:
  - financial criteria
  - operational criteria
  - accessibility of wells
  - regulation requirements
- Issues
  - Missing proper data and proper abandonment documentation
  - Large amount of efforts
    - Number of wells
    - Need for analyzing each well.

Thank you for attention

Acknowledgments

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