Study of the possibilities of CO_2 storage in the underground caverns of dissolution salt mines

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Abstract. Evaluating the possibility to store CO_2 in salt mines is made complex because of the lack of necessary data and different mechanisms that act on different time scales. This analysis can be made using traditional methods of geographical survey, lab experiments and digital simulations. Storing of CO_2 needs to be done in a stable geological area. The cavity must be thoroughly analysed for dimensions, depth, permeability and porosity. Based on studies made by the University of Petroșani some areas subject to collapse have been monitored using topography and sonic measurements with the aim to understand their possible evolution. Monitoring caverns and underground cavities is done using sonar. The sonar is a good instrument to manage a cavern, it increases its safety while it is being exploited and offers important data for the geomechanics model. CavInfo software package has been specially created to analyse and show individual caverns or systems of caverns. CavView II software allows for results of cavern sonar surveys to be displayed in a variety of ways, with the added possibility to compare surveys, analysis of caverns and export of data.

1 Introduction

Salt caverns are constructed in naturally occurring thick salt domes, deep underground. Salt formation can be found in almost every part of the world with some exception around the Pacific Rim. Salt caverns are a proven medium for hydrocarbon storage as salt acts as a natural sealant, trapping the natural gas inside the cavern. Salt caverns for gas storage use are formed with a leaching process by pumping hot water to dissolve the salt and removing the resulting brine via a single well, which then serves for gas injection and withdrawal. The storage capacity for a given cavity volume (several hundreds of thousands to several million cubic meters) is proportional to the maximum operating pressure, which depends on the depth [1]. Sequestration of CO_2 in salt caverns allows significantly higher sequestration efficiency (by at least one order of magnitude) than geological sequestration of CO_2 by

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other means. Although CO_2 is not as hazardous as methane and other natural gases commonly stored in salt caverns, CO_2 leakage should nevertheless be avoided. Geological sequestration of CO_2 is a mitigation option for significantly reducing CO_2 emissions into the atmosphere. This technology is immediately available and technologically feasible. A cavern filled with supercritical CO_2 will close in, thus reducing its volume, until the pressure inside the cavern equalizes the external stress in the salt bed. A single cavern of 100 m in diameter may hold 0.5 Mt of CO_2. A single cavern may not satisfy the needs of large CO_2 emitters, but arrays of such caverns can be built as a regional repository in the extensive and thick salt beds, without impairing general security of the repository [2, 3].

2 Objectives and challenges

The transposition and implementation of CCS Directive into Romanian legislation and the application of CO_2 capture and storage in the domains of Romanian economy determine a series of benefits, besides the ecological ones, and the contribution to providing the balance of the global climate system, such as:

- the increase of technical knowledge that regard the capture, transportation and storage of CO_2 and of technological innovation.
- the decrease of energy production costs in the case of the units that implement CCS technology, through employing the mechanism of trading the shares of greenhouse gas emissions.
- continuing to operate thermo-electrical plants that use lignite, including coal mines, which provide raw materials and related transportation networks.
- generating new jobs along the whole implementation chain, from planning, execution and operating to monitoring.
- generating new professional specializations and new educational programs for technical colleges and universities.
- determining the foundation of a new specialized field of industry.
- extending the implementation of CCS technologies to all the operators that generate greenhouse gas emissions.
- integrating Romania within the European CO_2 transportation infrastructure.
- increasing the capacity of exploiting the crude oil and natural gas reserves through injecting CO_2 in the deposits considered exhausted, owing to the increase of the retrieval coefficient.

3 Project desired implementation area

Figure 1 and Table 1 shows the characteristics of some closed wells in the Tg Ocna area. Based on a number of previous studies and monitoring the stability of these wells over the time, we have established the opportunity to use them as CO_2 deposits for as long as possible. Thus, closed wells S254, S251 and S268 are proposed for CO_2 storage. In case of a request from an investor, an offer could be submitted to NAMR (National Agency for Mineral Resources) to obtain the exploitation authorization for the geological storage of carbon dioxide, in accordance with the provisions of Government Emergency Decree no. 64/2011 on the geological storage of carbon dioxide, approved with amendments and completions by Law no. 114/2013 and its subsequent amendments and completions [4].

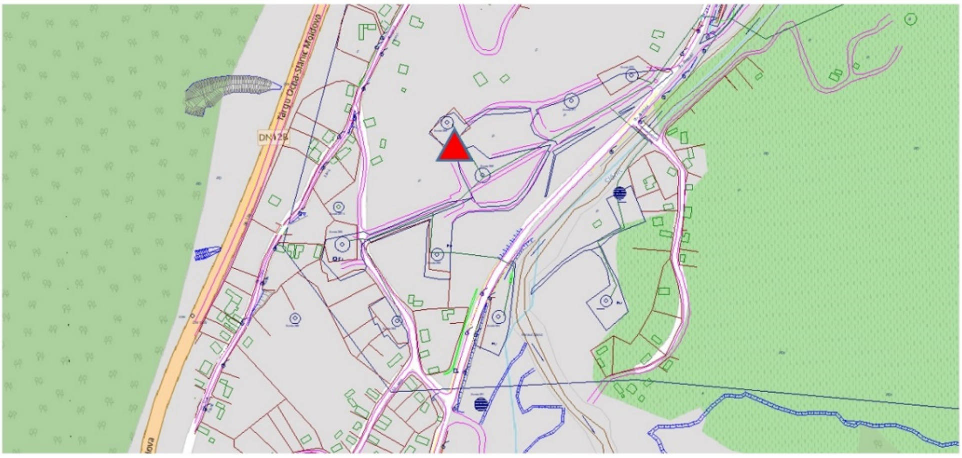

Fig. 1. Area of the well S268 under preservation in the mining perimeter of Targu Ocna.

Table 1. Some wells under preservation in the mining perimeter of Targu Ocna.

Well no.	Elevation variation [mm]	Period [years]	Volume of the cavern [m^3]	Diameter [m]	Wells for CO2 storage (Yes/No)
S254	0	150	580714.88	178	Yes
S255	-13.60	36.74	351193.25	91.6	
S282	-14.10	35	105416.82	44.6	
S251	+1.10	454			Yes
S280	-13.70 ÷ -14.5	34.4	200078.68	67.6	No
S275	-19.10	26		50	No
S268	+2.7 ÷ 4.9	∞			Yes
S280	-12.9 ÷ -14.5	34	200078.68	50	No

Relying on the research carried out between 2004 and 2015, the areas in danger of sinking were monitored through topographic and sonic measurements; meanwhile, the prognosis of the evolution of those areas was analyzed through mathematical methods based on geo-mechanic studies. As a result, relying on the analytical models, a prognosis of the phenomena for a medium and long term might be carried out. Maximal registered sinking is much lower than the maximum of 2.5 m, namely 1.7 m that represents the allowed sinking calculated in relation with the rheological parameters that might determine the beginning of the uncontrollable dislocation process. These results match the calculation regarding the safety coefficient of a cavern. In the analyzed case, R>1.6, meaning that resistance to rock is higher than failure tension, a fact that allows us to conclude that the analyzed cavern does not show any risks in terms of its roof, walls or surface stability.

FLAC 3D software for geotechnical analyses of the soil, rocks and underground waters will analyze the movements of the rocks in the salt mines. FLAC 3D employs an explicit formulation of the finite volume that captures the complex behaviors of the models displaying a nonlinear material behavior or are instable. The analysis may be applied to the engineering planning of civil, mining and geotechnical digging (for instance, slopes, tunnels, caverns, etc.) and constructions (dams, foundations, walls, etc.) on soil, intact rock and mass rocks (for instance, strongly fractured rock) [5].

The analysis of the phenomenon of sinking and change of the surface should be carried out in accordance to certain data regarding the physical and mechanical features of the rocks in the area as well as in accordance to the size of the caverns. Owing to the fact that the features of the rocks may be clearly observed even from the exploration stage, the main issue of the process of modeling is the identifying of the manner the size and shape of the cavern having resulted from salt dissolution progress.

4 Monitoring

Monitoring is a compulsory requirement demanded by governmental regulations and is also required for safety purposes. From a technical point of view, monitoring may provide important data for increasing productivity; it might avoid exploitation accidents, calibrate geo-mechanical models and increase exploitation safety.

A unitary monitoring system, called ecological or integrated, has been created that works globally. The questions that the monitoring system must answer are [6]:

- the purpose of monitoring
- monitoring control
- monitoring methods
- time scale and frequency of data collection
- the chosen variables and processes
- data analysis methods
- data interpretation
- the amount of data needed for a maximum of information.

So, the monitoring and surveying of land sink phenomena, both through exploiting salt in the underground owing to the dry method and owing to dissolution salt mining, is a subject of interest included within our preoccupations.

The monitoring was also imposed by the package of procedures created by National Agency for Mineral Resources from Romania, in order to geologically store carbon dioxide in our country [4].

The software package CavInfo Software Suite created by SOCON Sonar Control Kavernenvermessung GmbH, is specially designed for the analysis and display of individual caverns and entire cavern fields. It contains the individual programs CavViewII, CavMap and CavWalk Pro, which are perfectly coordinated with each other for smooth data transfer [7].

The echometric measurements for a single cavern may be analyzed by way of CavViewII. CavMap allows the simultaneous evaluation of several caverns belonging to a mining camp. CavLog allows the processing of the recording made during the measurements in the cavern. CavWalk Pro allows the users to create easily animated, complex 3D models, tridimensional measurements and a lot of other functions.

SOCON Sonar Control Kavernenvermessung GmbH is a services company specialized in monitoring caverns and underground cavities and, owing to its products, and become a part of the exploiting, exploring and research activities in the salt industry in our country.

Sonar (figure 2) measures the profile of the cavern and displays volumetric results in two-dimensional plans (2D) or in isometric and tridimensional ones (3D). Drilling may be carried out periodically in order to estimate the change of the volume of the caverns and of the profile of the caverns.

Sonar is a good device for managing caverns, increasing exploitation safety and offering important data for the geo-mechanic model. It is efficient for the topography of salt caverns with a radius up to 300 m.

Distance determining is made by way of measuring response time. The measuring principle relies on scanning the walls of the caverns point by point. Owing to the fact that sound speed depends on complex physical relations, it is determined in situ by way of a special drill module.

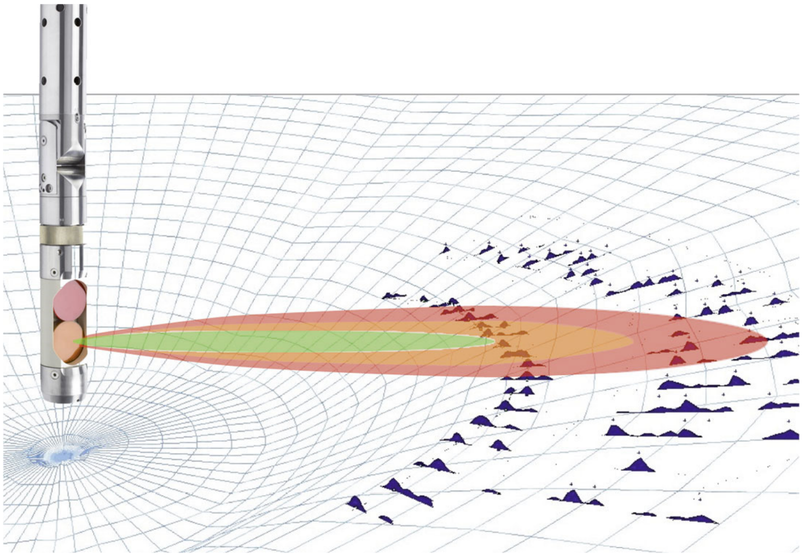

Fig. 2. Profile of the cavern measured by a sonar.

4.1 Interpreting echographic signals

Echographic signals are digitally registered, continually monitored and employed with a view to optimize measurement processes. All signals are transmitted as an overall diagram of the section together with the positioning data and are used for interpretation. Figure 3 shows a typical recording of the signal (echogram) for a horizontal section (360 degrees).

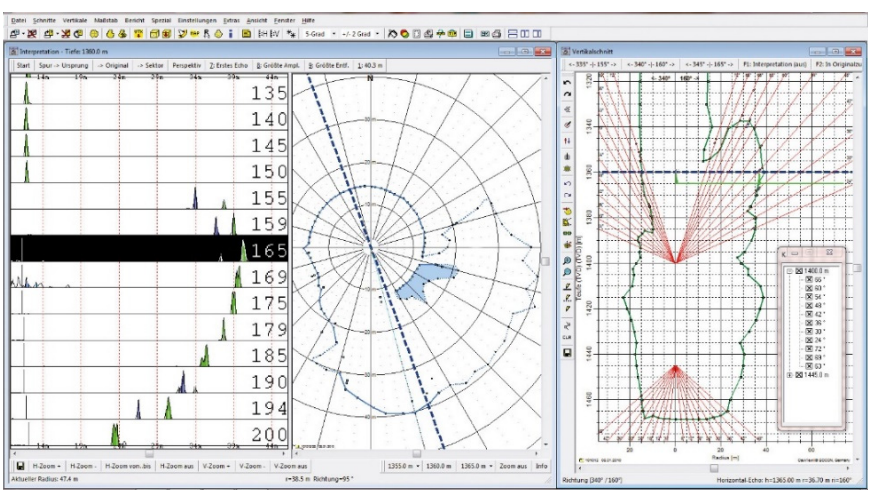

Fig. 3. Typical recording of the signal (echogram) for a horizontal section (360 degrees).

4.2 Cave integrity testing

SoMIT ® (Sunnar Mechanical Integrity Testing) drill, in Figure 4, is a drill conceived by SOCON with a view to be used in caverns for testing pressure leakage (losses), temperature or the change of the brine level.

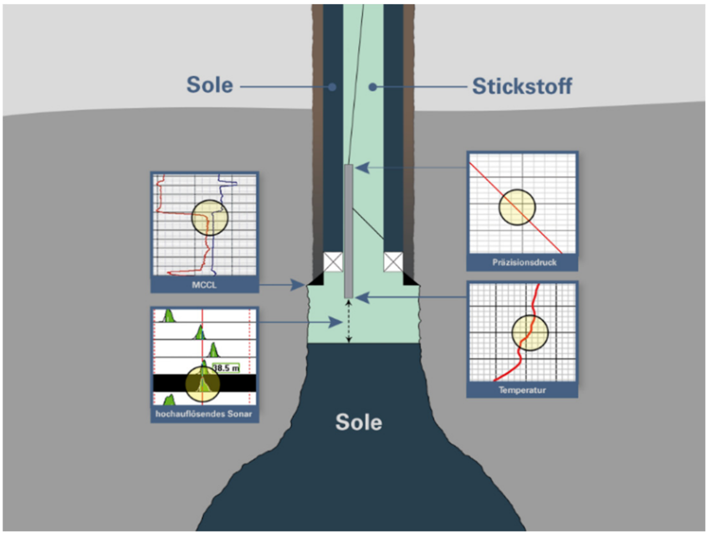

Fig. 4. SoMIT ® (Sunnar Mechanical Integrity Testing) drill.

4.3 Driling visualizinfg and analysis

CavView II is able to display the results of sonar drillings within caverns in a variety of manners (Figure 5). The integrated display options vary from horizontal and vertical sections to volume graphics and even tridimensional representations. Meanwhile, it includes functions for comparing drillings, for analyzing cavern's data as well as for data export.

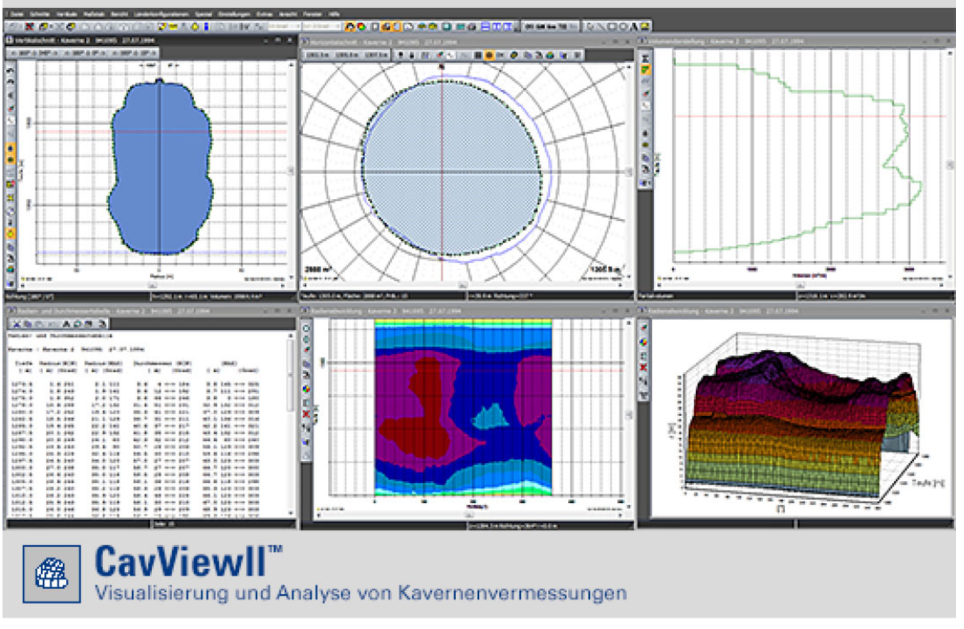

Fig. 5. results of sonar drillings displayed by CavView II.

4.4 Visualing and editing several caverns

CavMap allows the simultaneous display of several caverns (Figure 6). Such a cavern mining field may be visualized in plan. As a result, the user may separately determine, for each case, the most favorable type of display for caverns or pillars. Distances between adjacent caverns may also be determined as well as the visualization of various sections. Geological data may be correlated with the geometrical data of the caverns. Owing to the functions specially adapted for cavern fields and to its open architecture, CavMap is also suitable as a system of information about operations.

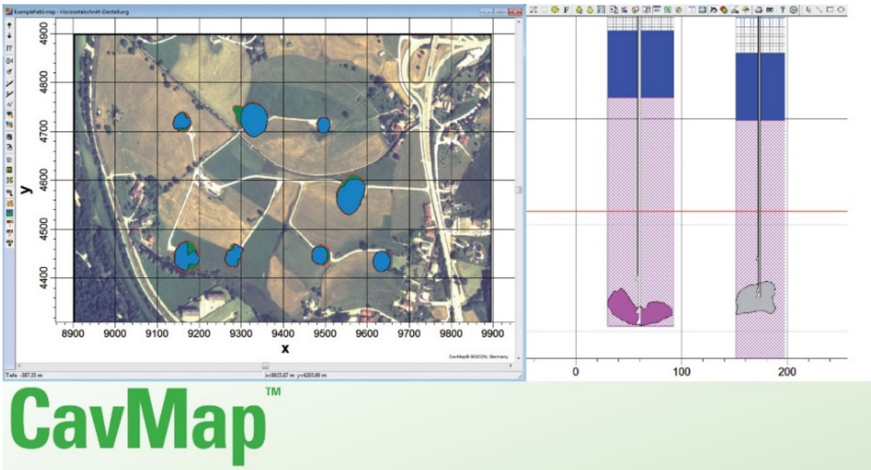

Fig. 6. Simultaneous display of several caverns by CavMap.

Fig. 7. CavWalkPro-3D display for measuring the caverns.

A series of software and CavWalkPro applications allow the user to literally move among the caverns and cavern fields, including the option of integrating the 3D models defined by the user as DXF format (for instance, geological formations in the roof or floor) from an outer source, see the Figure 7.

5 Conclusions

Studies were also made on the thickness of the pillars between the caves, the increasing of the cave numbers in a salt dome, the depth of the caves and the gas pressure introduced into the caves being variables that must be taken into account when calculating the stability of caves over time, for long storage periods > 1000 years. The allowable width of pillars between two adjacent bedded salt caverns, should be 2.0 – 2.5 times the cavern diameters when the vertical stress, deformation, plastic zone, safety factors, and seepage pressure are considered [8]. Once the caverns are closed and storage ready these will pass through the Mechanical Integrity Test (MIT) using pressures between 90 % and 120 % of the initial stress at the top of the cavern. The tests will be done with dryed compressed air in steps of 5 bars from 0 to 80 bars. After the tests, the brine will be reintroduced in the cavern thereby preventing the collapse of it. If the cavern passes the integrity and tightness tests, it starts the injection of CO_2 gas into the cavern. The problems of loss of cavern tightness storing CO_2 comes from problems in the well and never as a result of fractures or micro fractures in the cavern perimeter, as long as the correct geomechanical design of the cavern is made, especially in a cavern that will be abandoned indefinitely with pressurized CO_2 gas. Today there are only studies about the CO_2 interaction with salt rock, determination of CO_2 thermodynamic state variables, CO_2 phase diagrams, compressibility Isothermal curves, and geomechanical analysis of CO_2 storage in salt caverns [9].

University of Petroşani, in colaboration with private companies and also with the aid of the other research centers like National Research and Development Institute for Cryogenic and Isotopic Technologies from Ramnicu Valcea, National Agency for Mineral Resources, the National Salt Company S.A., National Research and Development Institute for Gas Turbines COMOTI fom Bucharest and so on, with National and European founds, is determined to participate in solving the major emerging global warming for CCS (Carbon Capture Storage) technologies with a key technology: to use more energy from renewable sources and minimalise the impact of using the fossil fuel in the energy production.

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