POSSIBLE RISKS OF CO2 STORAGE IN UNDERGROUND SALT CAVERNS

STELA DINESCU[1],SORIN MIHAI RADU[2], ADRIAN FLOREA[3],CIPRIAN DANCIU[4], OVIDIU BOGDAN TOMUŞ[5], SORINEL POPESCU[6]

Abstract: The potential of CO2 sequestration in salt mine cavities formed following salt extraction by dissolution is one of current trends considered to reduce CO2 emissions in the atmosphere, which can contribute to mitigating climate change. Research carried out by modelling and simulation of CO2 sequestration trough a case study involving the salt mine at Târgu Ocna has identified the possible risks rising from gas leakage.

Key words: risks, caverns, CO2 emissions, sonic cavernometer

1. INTRODUCTION

The sequestration of CO2 in geological strata presents and efficient option for reducing CO2 levels. Risk assessment enables the development of risk mitigation strategies. Identifying risks is therefore necessary to minimize the effects of potential CO2 leakage.

Risk assessment related to CO2 sequestration is carried out according to ISO standards. According to ISO 31000 [4] (Fig 1) risk assessment constitutes an integral part of risk management which in turns represents the process of risk identification and analysis.

Identifying of all significant risks related to gas leakage as well as the dangers which could prevent complete and permanent sealing represent and essential requirement. These are location specific, thus a careful characterization of the geology

[1] *Lecturer Eng., Ph.D., University of Petroşani, dinescustela@yahoo.com*
[2] *Prof. Eng., Ph.D., University of Petroşani sorin_mihai_radu@yahoo.com*
[3] *Assoc. Prof. Eng., Ph.D., University of Petroşani hadrianusf@yahoo.com*
[4] *Assoc. Prof. Eng., Ph.D., University of Petroşani danciu_ciprian@yahoo.com*
[5] *Lecturer Eng., Ph.D., University of Petroşani, tobogdan2002@yahoo.com*
[6] *Ph.D. student, University of Petroşani, sorin.popescu@toposystem.ro*

of the site is necessary to consider also generic risks and dangers for different gas escape routes.

As the CO2 risk assessment community is still relatively new, there is currently no consensus on appropriate risk methodologies, largely due to a lack of understanding of the behaviour of geological reservoirs and the effect on risk assessment that this entails.

Existing projects use a variety of tools, from the simplest to the most sophisticated and probabilistic. As a single assessment standard would not be useful in all cases, a set of possibilities and risk assessment tools is recommended to establish the best possible risk assessment [3].

The potential risks of storing CO2 in a geological reservoir can be divided into several categories, depending on their main causes: CO2 leakage, seismicity, soil movement and removal of salt solution.

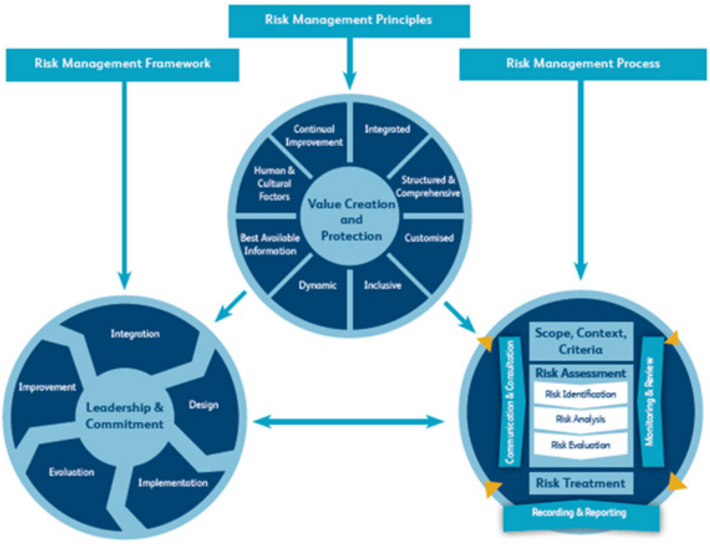

Fig. 1. Principles, framework and process of risk management according to ISO 31000: 2018

Sensitivity analysis and modelling can be used to create scenarios for different hazard mechanisms and to determine critical parameters that could lead to potential leaks.

It is important to consider how the risks and risk profile evolve over time during the life cycle of the storage. This should help by presenting how different risks evolve (i.e., increase / decrease) over time, where within the storage reservoir and when during the life cycle they are most likely to occur, thus providing a quantitative assessment of the risks in time [2].

As with other geological storage options, the geological screening is important for selecting a suitable storage site. In general, existing caverns may not be suitable for CO2 storage due to the previous dissolution practices, which did not take into account the possible use of the site (post-closure) for gas sequestration.

2. **POSSIBILITIES OF CO2 STORAGE AT TÂRGU OCNA SALT MINE**

The rock salt deposit from Târgu Ocna is located on the middle course of the Trotuş river, at its confluence with River Slănic located on the Feţele Târgului hill on the left slope of the Vâlcica brook. This area is located within the perimeter of Târgu Ocna, Bacău County.

Extraction of the Gura Slănic salt deposit is carried out using wells by the process of kinetic dissolution, the dissolving agent being water or unsaturated brine. The site belongs to salt mine Salina Târgu Ocna within the National Salt Company-SALROM.

The extraction of salt by dissolution is carried out in two areas: the western field, which includes a number of 29 extraction wells, located along the western bank of the valley Slănic brook, (with one exception, well 363) and the eastern field, which entered production relatively recently, located on the hill on the right bank of Slănic brook (Fig 2) [1].

The wells in the western field are numbered 251, 253-260, 263-278 and 280-285, and those in the western field 1E, 4E, 5E, 6E, 11E and 12E (Fig 3) [1]. 9 of the 69 wells which were drilled did not intercept the salt deposit.

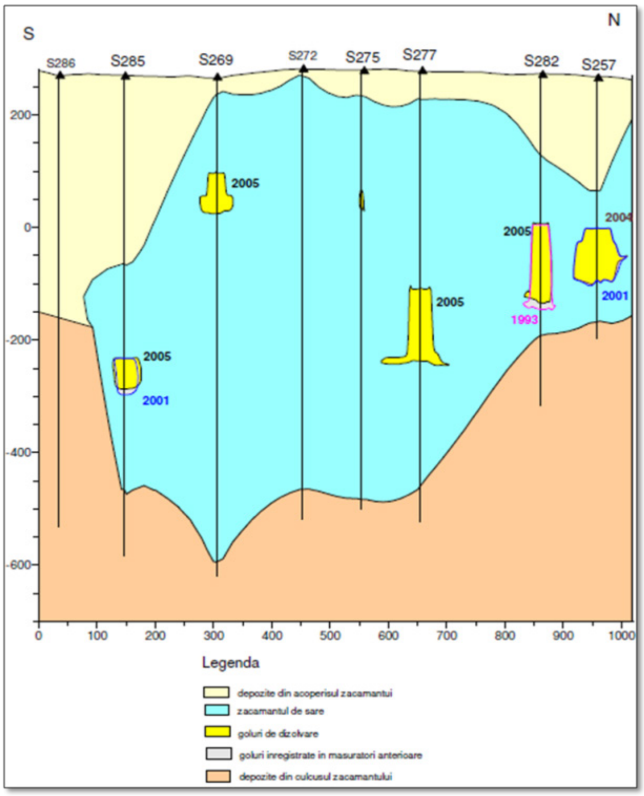

Fig. 2. Geological section through the Târgu Ocna salt deposit [1]

In order to control and coordinate the operation horizontally, the extraction is done in steps with heights between 10 m and 30 m using an insulating fluid, which ensures the tightness of the ceiling of the dissolution chamber. The evolution of the dissolution chamber is performed with a sonic cavernometer.

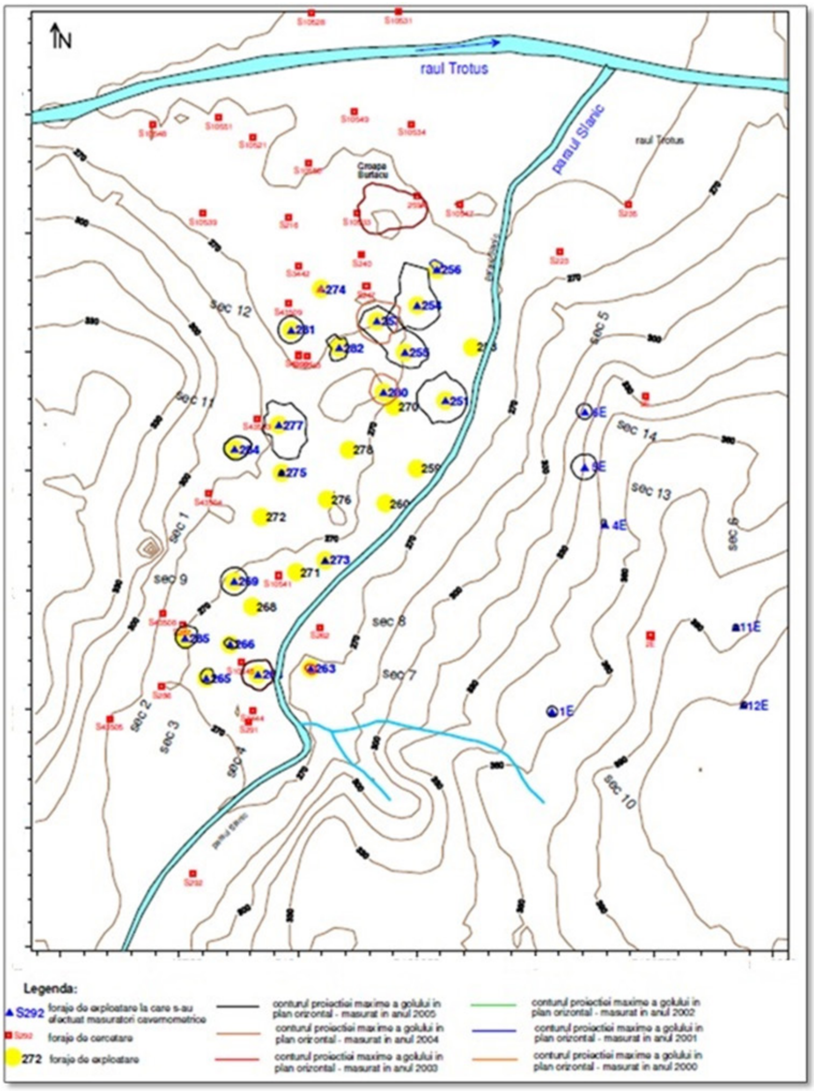

Fig. 3. Surface level curves, sections and boreholes positions at salt deposit Tg. Ocna [1]

In the region there are sedimentary formations made up of terrigenous marine formations of flysch and molasses, as well as evaporation deposits with gypsum, rock salt and potassium salts.

Within the Târgu Ocna region three tectonic units overlap vertically: the medial-marginal area, the external area and the peri-Carpathian area.

The problem of tracking the movement and deformation of the soil surface under the influence of caves resulting in the process of salt extraction by dissolution has special implications regarding the protection of mining surfaces.

Currently, abandoned mining fields present a real danger because of the dissolution wells, through the uncontrolled dissolution process that generates caverns with safety floors, whose thickness no longer corresponds in terms of load-bearing capacity.

The hazard characterization must cover the full range of potential operating conditions to test the security of the storage reservoir. These hazards include geological escape routes, man-made escape routes (e.g., wells and mining) and other hazards caused by the mobilization of other gases and fluids by CO2 (e.g. methane).

3. CAVITY CONTAINMENT TESTING

Consider a hypothetical situation, in which there is a cavity full of brine at a hydrostatic pressure, *pc* of 1.2 × 9.81 × z [MPa], where z is the depth in kilometres. This gives *pc* ~ 14 MPa at 1,200 m depth [1][5].

A series of tests are performed to accurately determine the behaviour of the salt and of the cavity. These tests may include several different methodologies designed to assess both short-term and long-term deformation characteristics.

• Salt solution flow behaviour can be evaluated by a pressurization experiment. The pressure in the cavern, *pc*, is increased or decreased by 1-2 MPa, the well being sealed, and the response to Δp over time is analysed to calculate the elastic properties of the salt in the short term (weeks or months).

• A larger scale test can be performed on the entire salt solution flow.

With a constant *pc* of 5 MPa above the hydrostatic pressure, the brine flow $\Delta Vc / \Delta t$, is carefully monitored and analysed for a few weeks or months.

• The “natural” pressurization in the cavity can be assessed by closing the surface valves on the access wells and measuring $\Delta pc / \Delta t$ for a period of weeks to months. This pressurization takes place slowly due to the seepage response of the salt deposit. These data provide the answer to the seepage of the rocks.

• A cavity integrity test can be performed using a short-term pressure of 24-26 MPa and comparing the $\Delta Vc / \Delta t$ response with the results of previous tests. This test only takes a day or less. The pressure transducers installed behind the operating column will detect any pressure change of the fluid along the housing.

• Finally, a short-term dynamic pressure test (pressure oscillation test) can be performed to determine both the cavity volume and its elastic response.

The data are analysed carefully with appropriate methodologies and using expertise in the interpretation of this information.

The infiltration mechanism

In general, the fluid flow in a porous medium conforms to Darcy's equation:

$$v = \frac{-k}{\mu}\frac{dP}{dl} \tag{1}$$

where: *K* represents the permeability of the rocks and *dP/dl* pressure gradient.

For the gas flow in an intermediate non-salt layer, due to its very low permeability, the effect of gas flow at the interface between the intercalation layer and the salt layer must be taken into account. Then Darcy's classical theory is modified by taking into account the Klinkenberg effect, usually shown by an additional relation:

$$K_g = K(1 + b / p) \tag{2}$$

where: K_g gas permeability;
K rock permeability;
b Klinkenberg coefficient
p average pressure in the porous media.
Parameter *b* is given by the following equation:

$$b = 16c\mu / d\sqrt{2RT / (\pi M)} \tag{3}$$

where: *c* constant (in practice equal to 0,9);
μ gas viscosity;
M gas specific constant;
d particle diameter ;
R = 8314m^2 / (s·K)
T temperature (in Kelvin)

4. MODELLING AND SIMULATION

The calculation domain is divided from 920 to 1010 meters depth. Both the left and right boundaries are 150 meters from the centre of the cavity. According to the field survey, the rock formations and the shape of the cavity are illustrated in Figure 4. The figure shows that there is a 2 m intercalated layer at the top and another 3.8 m intercalated layer at the lower part [1][5].

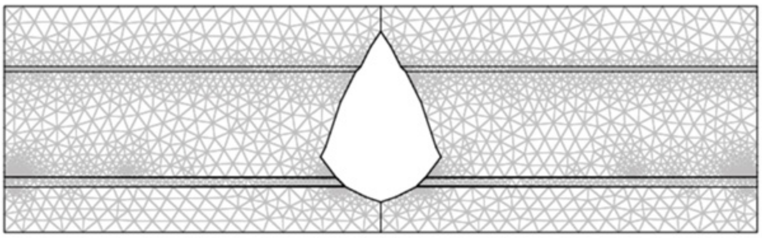

Fig. 4. Model

It is assumed that the interface of the lower inclusion is damaged and microcracks appear. The microcrack will gradually disappear as the distance along the interface increases. During the simulation, both the salt and the intercalation area are considered as porous media; their intrinsic permeabilities are 1×10^{-20} m^2, respectively 1×10^{-14} m^2 determined from laboratory experiments.

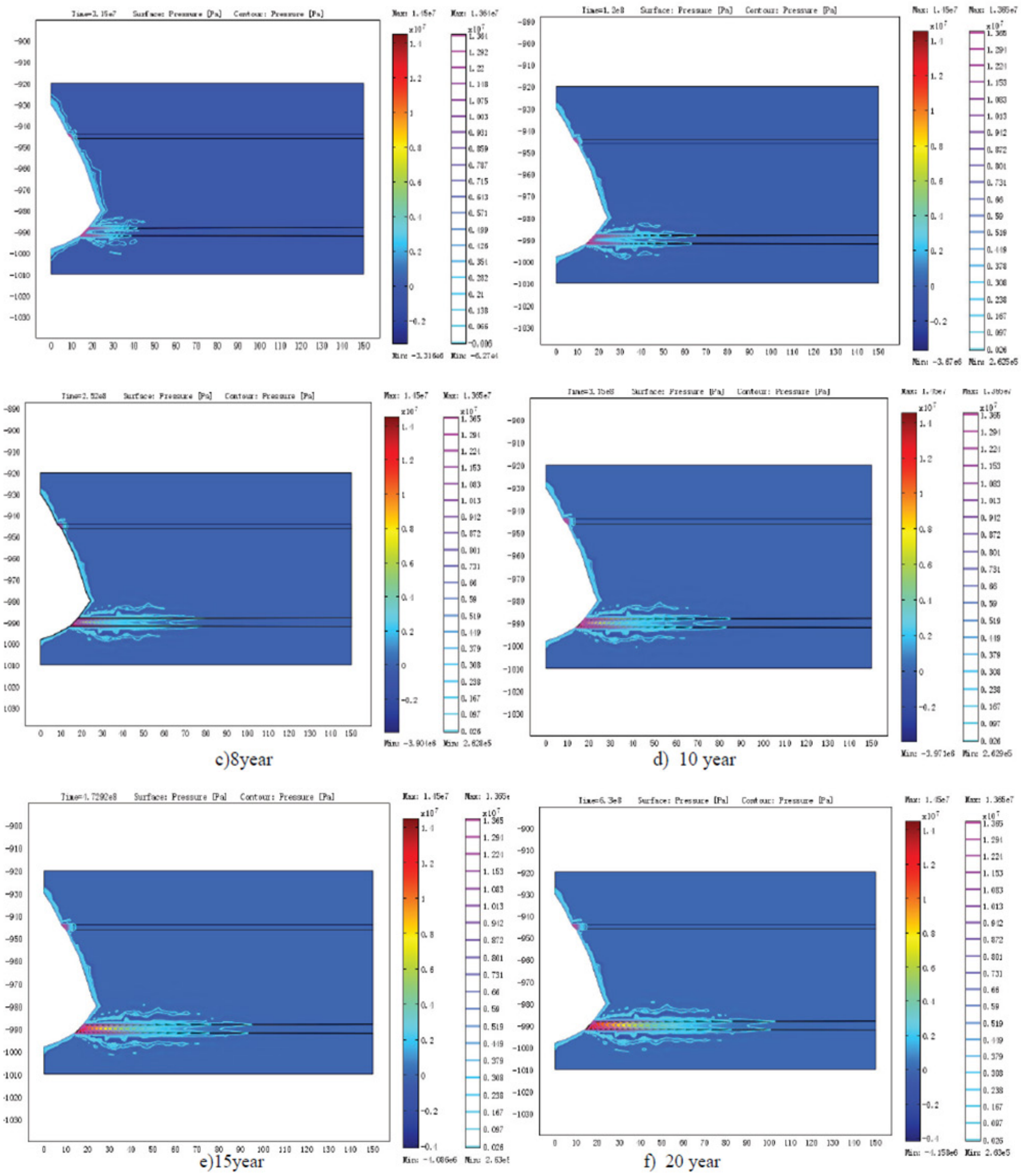

Fig. 5. Gas pressure distribution after 20 year storage [5]

The damaged interface area is composed of microcracks and clay. By using the double-medium mesomechanical model, we can obtain by calculation an equivalent permeability of 1×10^{-10}. Other parameters of natural gas include its density (80kg / m^3) and viscosity coefficient (1.81×10^{-5} Pa•s).

Given the symmetry of the model, in order to save computational time, only its right half is adopted for the calculation of infiltrations.

Simulation under 10MPa operating pressure[5]

Figure 5 shows the gas pressure distribution, after a gas storage period of 1 year, 4 years, 8 years, 10 years, 15 years and 20 years. These figures show that the infiltration rate along the damaged interface area of the lower sterile layer is much faster than the other areas. In addition, due to the existence of a damaged area, the gas moves faster in the lower layer than in the upper layer.

As the period of operation increases, it is found that more and more pressurized gas infiltrates over longer distances. Therefore, during the construction and operation of the Târgu Ocna salt mine, it is necessary to investigate the infiltrations along the interface area, which is the critical factor in controlling gas leaks from the salt cavern.

Figures 6 and 7 provide details of gas pressure distribution along the cracked intercalated top layer and the damaged bottom interface, respectively. Thus, as the operating time increases, the gas seeps into more and more areas. As the permeability of the upper intercalation layer is lower, it is shown that the affected area is also small, even after 20 years of operation; the affected distance is only 10 meters (Fig 6).

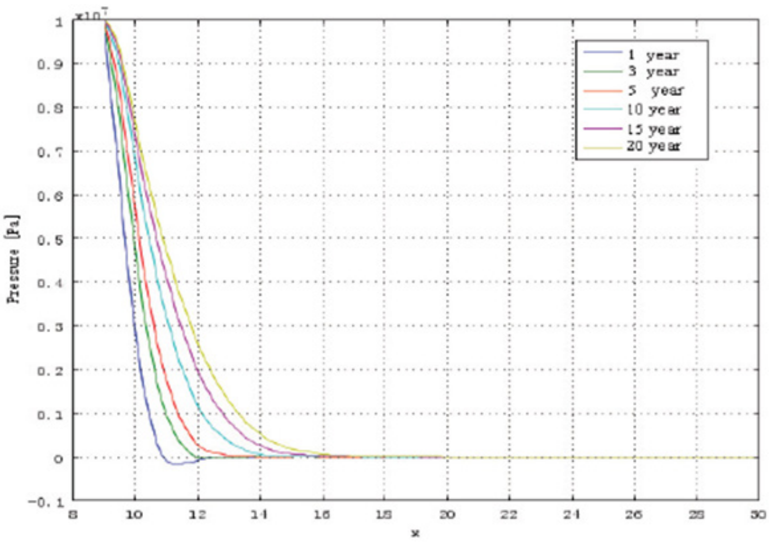

Fig. 6. Distribution of gas pressure along the upper intercalated layer[5]

Therefore, the well-cemented and uncracked intermediate layer is considered to be less affected by the stored gas. On the contrary, in the lower intercalated and damaged layer, the gas is infiltrated: in the damaged interface (Fig 7) the main affected range (where the gas pressure is higher than 0.5MPa) extends to 22 meters, 34 meters, 42 meters, 54 meters respectively , 63 meters, 72 meters from the centre of the cave after 1 year, 4 years, 8 years, 10 years, 15 years and 20 years of operation, respectively.

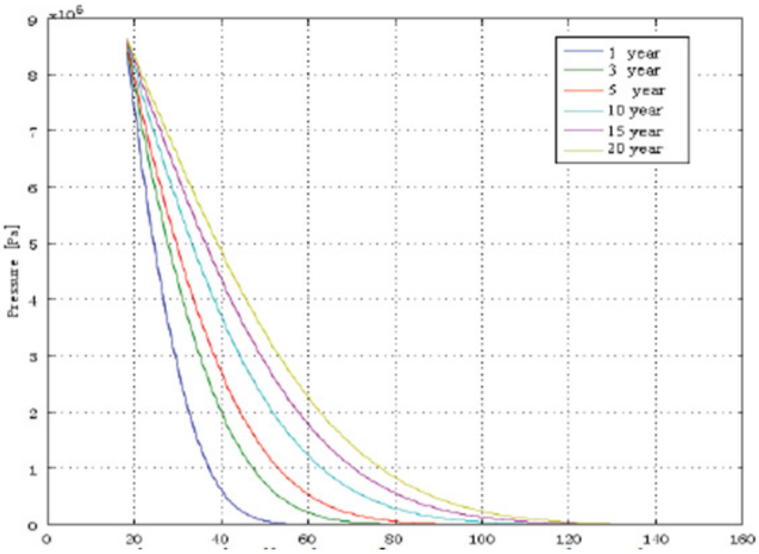

Fig. 7. Distribution of gas pressure along the damaged area near the interface[5]

5. RISK MONITORING INSTRUMENTS

In underground rock engineering, many of the sources of risk or danger arise from uncertainty or geotechnical error. The nature of the uncertainty and errors that provide sources of geomechanical risk in geotechnical engineering is widely presented in the literature.

The CavInfo Software Suite software package created by SOCON Sonar Control Kavernenvermessung GmbH is specially designed for the analysis and display of individual caverns and entire cavern fields.

The sonar measures the cave profile and displays volumetric results in two-dimensional (2D) or isometric and three-dimensional (3D) planes. Drilling can be carried out periodically to estimate changes in cave volume and cave profile. Sonar is a good device for managing caves, increasing operational safety and providing important data for the geo-mechanical model. It is effective for topography of caves with a radius of up to 300 m.

The distance is determined by measuring the response time. The measurement principle is based on point-by-point scanning of cave walls. Due to the fact that the speed of sound depends on complex physical relationships, it is determined in situ by means of a special drilling module.

6. CONCLUSIONS

In this paper we presented possible risks of CO2 storage in underground caverns resulting from the extraction of salt by dissolution from the mining perimeter Târgu. Ocna. We presented a numerical simulation of the gas leakage mechanism from a salt cavern - hypothetical case study.

The following conclusions are drawn:

- If the interface between the salt and the intercalated layer is damaged, it will become the main route of natural gas leaks, which has a significant influence on the sealing performance of cavities.
- There is very little gas leakage between the salt layer and the undamaged intercalating layer and therefore they can be considered as impermeable areas.
- The results of the simulation at different operating pressures illustrate that, with a higher operating pressure, natural gas spreads faster at the beginning of the storage years, but over time this phenomenon will stabilises.

However, typical failure scenarios of CO2 storage include leakage along the well, destruction of the wellhead, and leakage through existing or induced defects and fractures. Clearly, it is necessary to ensure, as far as possible, that injected CO2 remains safe underground.

REFERENCES

[1]. **Dinescu, S.** *Cercetări privind evaluarea și gestionarea riscurilor de depozitare a CO2 în minele de sare,* Contract de cercetare științifică universitară nr. 6454/07.10.2021, Universitatea din Petroșani, 2021**.**

[2]. **Dodds, K., Watson,m., Wright, I.** *Evaluarea metodologiilor de evaluare a riscurilor folosind proiectul de stocare a CO2 In Salah ca istoric de caz*. Proceedings of GHGT10 Conference (in press), 2010.

[3]. **Gerstenberger, M. C., Christophersen, A., Buxton, R., Allinson, G., Hou, W., Leamon, G., & Nicol, A.** *Evaluarea integrată a riscurilor pentru CCS. Energy Procedia,* 37, 2775–2782. https://doi.org/10.1016/j.egypro.2013.06.162I, 2013.

[4]. **ISO**, 2018. Managementul riscurilor — Orientări (No. ISO 31000), 2018.

[5]. **Huang, X, Xiong, J.** *Numerical Simulation of Gas Leakage in Bedded Salt Rock,* 12, 1877–7058 2011 Published by Elsevier Ltd. https://doi.org/10.1016/j. egypro.2011.05.040, 2011.

[6]. **Tomuş, O. B., Andraş, A., Andraş, I.** *Study of the dependence between the cutting direction relative to stratification and the digging characteristics of lignite in Oltenia coal basin (Romania).* International Multidisciplinary Scientific GeoConference: SGEM, 17(1.3), 825-830, 2017.

[7]. **Dinescu, S., Andraş, A.** *Environmental friendly equipment and technology for underground civil excavations*. Annals of the University of Petrosani, Mechanical Engineering, 10, pp. 47-52, 2008.