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АККУМУЛИРОВАНИЕ И ХРАНЕНИЕ ЭНЕРГИИ В ПОДЗЕМНЫХ ПОЛОСТЯХ

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Аннотация: Энергетическая промышленность оказывает значительное воздействие на окружающую среду во всем мире, что включает в себя загрязнение воздуха, воды и почвы, а также изменение климата. Энергетический сектор как сильный источник загрязняющих веществ негативно влияет на экосистемы и биологическое разнообразие в Румынии. Для решения задач снижения выброса парниковых газов, поставленных Евросоюзом, требуется интегрировать источники возобновляемой энергии в электрическую сеть, в то время как Национальная Энергетическая Система не соответствует необходимым стандартам. В этой связи, требуется аккумулировать большие запасы энергии. Имеющиеся на территории Румынии подземные пустоты в соляных массивах горных пород позволяют хранить большие объемы горючих флюидов при минимальном воздействии на окружающую среду. Изучение опыта, полученного в данной области в других странах, может помочь в выборе и адаптации соответствующих технологии для использования в различных условиях в Румынии.

Ключевые слова: энергия, технологии подземного хранения, водород, соляные шахты, извлечение, окружающая среда.

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Research on storage of energy in underground caverns

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Abstract: Globally, the energy sector has a significant impact on the environment, by polluting air, water and soil and contributing to climate change. Also, in Romania, the energy sector remains an important source of emissions and activities in this field are likely to affect ecosystems and biodiversity. Achieving the objects of the European Union regarding the reduction of greenhouse gas emissions, requires the integration of renewable energies in the electricity grid, which implicitly leads to problems of inadequacy of the National Energy System. Large-scale energy storage can provide the means to solve these desires. The underground caverns in the salt massifs of our country, create the possibility of storing large volumes of combustible fluids with minimal impact on the environment. By gaining experience in the field of other countries, the working technologies can be chosen and adapted to the different field conditions in Romania.

Key words: energy, underground, storage technologies, hydrogen, salt mines, extraction, environmental.

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Introduction

Achieving the objectives of the European Union on reducing greenhouse gas emissions requires the integration of renewable energies into the electricity grid, which implicitly leads to National Energy System (SEN) inadequacy issues. Large-scale energy storage can provide the means to meet these desires. The underground tanks in the salt massifs of our country creates the possibility of storage in large volumes with minimal impact on the environment. Gaining experience in the field of other countries, working technologies can be chosen and adapted to the different field conditions in Romania.

The strategic package "20—20—20" approved by the European Council in 2007 decided the strategic guidelines at EU level by 2020. This strategic package aims to achieve the following objectives:

- reduction of energy consumption by 20% compared to the evolution that would have been recorded in the absence of energy efficiency measures;
- increasing the share of renewable sources in the total gross final energy consumption to 20%;
- reduction of CO2 emissions by 20% (compared to the reference year 1990).

Even if the initial goals were set for 2020, the major objective of European policies is for the year 2050, that is to reduce by up to 85—90% the greenhouse gas emissions.

The spectacular decrease in renewable energy production costs, the promise of commercial efficient electricity storage in the coming years, electricity output, the progress of energy management systems, are challenges to the conventional paradigm of production, transport and energy consumption.

The increasing share of wind and photovoltaic production, with intermittent generation and stochastic profile, raises the issue of National Energy System SEN and electricity market function rules.

As critical infrastructure elements, transmission systems, distribution and energy storage are essential for good economic and social operation.

Globally, the energy sector has a considerable impact on the environment through air, water and soil pollution, and in terms of GHG emissions and climate change contribution. In Romania too, the energy sector remains an important source of emissions, and some activities are likely to affect ecosystems and biodiversity.

Over the past decade, significant progress has been made in Romania's energy sector to limit the environmental impact. However, considerable efforts are still needed for the energy sector to contribute to Romania's transition to an economy based on the principles of sustainable development.

The application of research in the energy sector also needs partnerships with the energy industry. Thus, Romanian research will be able to contribute to maintaining a high level of education, to ensuring the necessary human resources to both the public and private sectors and, by implication, to increase Romania's energy security.

The issue of energy storage concerns at the highest level both decision-makers and university and research environments in the field, being an important chapter in the energy strategies of large energy-producing countries [1].

Many universities and several research institutes, such as the National Institute for Electrical Engineering R&D (ICPE), the Institute of Material Physics — the Energy Efficiency Laboratory, the National Center for Hydrogen and Fuel Cells and the National Research Institute for Cryogenic and Isotopic Technologies from Râmnicu Vâlcea (INCDTCI) with specialized laboratories have important results in the research activity in the field of energy production and storage. It is important to point out that the work of researchers from INCDTCI Ramnicu Vâlcea, together with people from other related fields, aims to establish new standards and international cooperation in the national institutional framework Romanian Standardization Association (ASRO) [2].

The main purpose of research is to design an efficient energy storage system that can be applied on a national scale.

Underground energy storage technologies

Power-to-gas is a technology that uses electrical power to produce a gaseous fuel [3]. Through Power-to-gas technologies, energy from electricity can be stored and transported in the form of compressed gas, often using existing infrastructure for long-term transport and storage of natural gas. Among the most frequently used power-to-gas technologies are [4]:

1. ***Power-to-hydrogen —*** proposes that hydrogen obtained through the electrolysis process be injected directly into the natural gas network. Here it should be pointed out that there is a certain limit for the volume of hydrogen that can be injected into the natural gas network. With reference to some research, a safe value can be considered to be less than 10% [5].

2. ***Power-to- methane-*** Carbon dioxide (CO_2) resulting from the capture process from industrial producers (power plants, steel combined, cement or petrochemical combined factories) will ensure the necessary of carbon dioxide that will be combined with hydrogen resulting from the electrolysis process in the methane reaction, resulting in SNG (Natural Substitute Gas). The advantage lies in the fact that NgS can be stored and transported by the natural gas network without any further modification of the infrastructure or installation of end-users. The disadvantage lies in the fact that the CO_2 capture process is costly and therefore the method is currently financially unfeasible [6].

Compressed Air Energy Storage (CAES) proposes to store energy in large quantities using compressed air. Along with hydro-plants with pumping accumulation, CAES is the only technology that can store a quantity of energy of the MW order.

The appropriate geological formations for CAES can be salt caverns, depleted hydrocarbon fields, aquifers and abandoned mines [7].

Pumped Hydroelectric Energy Storage (PHES). The system is not a new idea, it is an adaptation of the concept of conventional hydraulic pumping, in which two surface water tanks positioned at different heights are used to store and recover the potential energy of water. The lower water tank is an underground cavity, reducing the environmental impact because dams are eliminated and thus minimize habitat destruction [8].

Thermal Energy Storage (TES). It can store heat by cooling, heating, melting, solidification or vaporization of a material, such as hot water. The underground is suitable for storing heat because it has a high thermal inertia, that is, if not disturbed below a depth of 10 — 15 m, the soil temperature is poorly affected by local climatic variations and maintains a stable temperature. TES can efficiently store heat from summer ambient air, solar energy or heat from industrial processes for long or short-term storage, and then in winter to be reused in the preheating of homes, or in industrial processes. The use of such a system is known, by storing mining water in an old operation, for their reuse in the urban heating system (eg. The Netherlands) [9].

Gasification of coal underground by burning a whole layer of coal without being extracted through traditional methods, followed by subsequent capture of gases and their transformation into fuel. The technology consists of carrying out a flat-end drilling to the coal layer, after which the drilling is cemented and isolated. Subsequently, another drilling is carried out from another part of the deposit, after which one horizontally, until near the first. Then "burn" the coal layer and through the second drilling oxygen is pumped to maintain combustion. The resulting gases are sucked up to a unit that converts the resulting synthetic gas into fuel. The method is not new, it is 60 years old, but it's only now that it's starting to be used.

Storage of energy in the form of hydrogen, carbon dioxide or compressed air can be done both underground in salt mines or at the surface in special containers. The costs necessary to build such tanks given the special materials used and their volume, lead to this method being less used.

The choice of different storage variants will be made according to the range of hydrogen use as an alternative solution to current fuels: oil products, methane gas or electricity. Large quantities are in use liquefied hydrogen tanks, and small quantities are mainly used for metal hydride [7].

The main underlying parameters when choosing an energy storage technology are [10]:

- The range of powers in which it operates (consumption and supply of energy from the network);
- If there are still close technologies in the area where the technology is to be located;
- Storage system charging/unloading time;
- Time to respond to the network's requests,
- The life of the entire storage system,
- Efficiency,
- Investment costs by kW and kWh.

Despite its low efficiency, the development of hydrogen-based storage technologies is recommended due to the fact that it provides high storage capacity compared to other storage technologies such as CAES or PHES, providing the possibility of large-scale storage over a long period of time.

Speaking of the functioning of a national system with millions of consumers, it is obvious that we need to consider the possibility of storing hydrogen in very large quantities.

Salt mines caverns, formed as a result of salt mining by dissolution, can become ideal tanks for storing hydrogen.

Possibilities of hydrogen storage in salt mines

In Romania, where there are traditions in salt mining since Roman time, two forms of extraction are known: extracting salt into the salt and extracting salt by dissolution, where by SALROM-National Society of Salt, extracted and extracted salt at the level of: Ocna Dej, Tg. Ocna, Ocnele Mari, Slănic Prahova, Praid, Cacica, and Ocna Mures.

The operation of salt by dissolution using wells in Romania is applied to four salt deposits, namely Ocna Mureş, Ocnele Mari, Târgu Ocna and Cacica (fig. 1) [11].

Salt exploitation can be achieved through dry methods or dissolution [12].

Dry methods used in salt mining in Romania are:

— Operation in large trapezoidal rooms has long been a modern method, which consists of underground exploitation at certain depths, by digging horizontal opening galleries from the access bridge and extracting (vertically), from which it is dig downed (descending) by successive cuts in large operating rooms, rooms that have different sizes, but which can reach 50—60 m deep, 30—40m. The method was used in Targu Ocna, Slănic Prahova, and Ocna Mures.

— Operation with small rooms and square pillars consists of small room operation, with transport possibilities and total mechanization, high efficiency, no large losses in much lower piling and ceiling control possibilities and risk avoidance. The method also allows transport by strip, being the one that has been used most lately. We practice it as a unique method at Ocnă Dej, Slănic Prahova, or combined at Ocnele Mari, Targu Ocna, and Praid. Operation of salt by dissolution was imposed later over time due to geomining conditions, high efficiency, determined by productivity, cost and energy consumption much different from classical operation, and the development of drilling and extraction technologies.

There are several technical variants of extraction by this method of dissolution, two being those that are used in our Salt mining: Targu Ocna, Ocnele Mari, Ocna Mures and Cacica [11].

In salt mining in Romania two dissolution methods are used which shows three operation stages shown in fig. 2, (a-individual probes, b-probes in the battery primed by classical dissolution, c-probes in channel primed by hydraulic cracking):

— 2-cell operation: operation/extraction and intermediate water injection;

— cemented operating column operation.

In addition to the advantages described above, the method of dissolution also has shortcomings: a more difficult control of the shapes and dimensions of the caverns created, uneven dissolution of the minerals with consequences for the control of the resulting caverns and the sterile in the massive. The biggest problems are the cavern measurements of the gaps created, which are done with the sonic cavern meter and leading the dissolution directions in order not to affect the resistance structures of underground gaps [12].

The underground storage conditions for hydrogen are similar to those used for the storage of natural gases, depleted gas fields, saline aquifers and salt caverns, but due to its small molecular size, hydrogen diffuses easily and therefore requires airtight storage tanks. Salt caverns are the best option for storing hydrogen, as salt is inert in terms of hydrogen and is extremely resistant to pressure. The possibility of storing hydrogen can also be considered in porous environments, depleted oil fields and abandoned mines. Several examples of underground gas storage facilities are shown in Figure 3, [9]. There are currently only three locations around the world where hydrogen storage has been implemented, two of which are in the US and one in the UK, all in salt caverns.

Gaps in the underground after operation of salt by dissolution require permanent monitoring to prevent any unwanted situations that may occur. It is necessary first of all to know the exact conditions of the in-situ at the time of closing the probe.

The monitoring itself takes into account the following aspects [11]:

1. **Geomechanical aspects**

— Visual tracking of the surface around the well/field of wells;

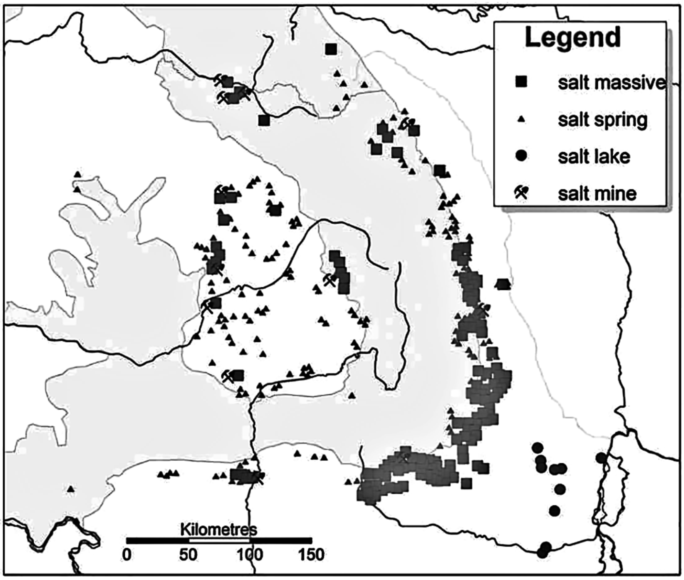

Fig. 1. Salt exploitations in Romania

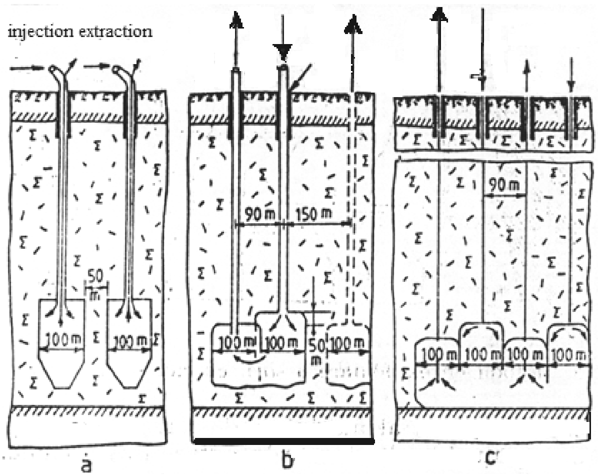

Fig. 2. Different variants of salt exploitation by dissolution

— Periodical well pressure measurements;

— Topographical measurements of the well and its components (feet and flanges), and the area above and in the vicinity of the dissolution gaps by landmarks located according to the conditions resulting from the operation.

— Analysis of the stability of the roof rocks and the marginal and intracameral remaining pillars. These topographic measurements are of particular importance in establishing and developing the risks of overflow, which can occur at any time due to the gaps resulting from the dissolution of salt, causing horizontal and vertical movements.

— Following topographic measurements, the deformation of land surface and buildings is determined.

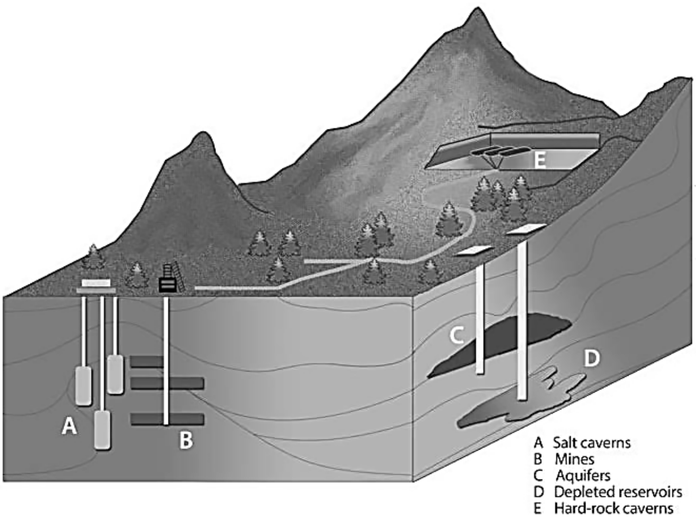

Fig. 3. Types of underground gas storage facilities

— The analysis of the strain state for a well or well field is the result of monitoring. This analysis should be carried out after each cavernometric measurement, where changes in the gap geometry have been identified.

— Determination of the strain state can be done both with programmes based on numerical methods and directly through the micro seismic station (where one exists).

2. **Geophysical monitoring**

— Periodic cavern metric measurements.

— Gravimetric measurements.

— Electrical measurements.

— Geothermal measurements.

— Micro seismic monitoring where required.

Cavernometric measurements provide data on the shape, dimensions and volume of gaps, maximum radius and dissolving preference direction, massive location and land surface. The processing of this data leads to the establishment of technological solutions to reduce the risk of environmental damage, and measures can be taken to avoid or mitigate destructive effects.

Energy storage cost parameters

The cost of a plant can be divided into the cost of capital required for construction and variable costs related to operation [13].

The cost of storage depends on a number of factors:

— Investment cost [euro/kW];

— Energy cost [euro/kWh];

— Maintenance cost [euro/kWh];

— Efficient [%];

— Cycle duration [%];

— Life duration [years];

— Number of decoration cycles per day;

— Installed power [kW];

— Power consumed [kW].

Large-scale storage in CAES, PHES, Power-to-Gas systems, need a major investment, but if the installed power is high, then the cost becomes a low one. A number of studies in Germany show a global cost of hydrogen of 4—6 Euro/kg. The majority of costs are on the one hand related to investment costs for electrolysis and on the other hand the costs of electricity consumption for hydrogen production.

The impact of the investments needed to arrange the cavern is rather small relative to the other costs, and the impact becomes even smaller once the size of the cavern increases.

Underground planning should take into account the land surface conditions and the available infrastructures. Thus, an additional set of general criteria should be considered for the different types of tanks and related to operational, construction or environmental factors, which include:

- Inexistence of environmentally sensitive areas and protected areas for ground water;
- Unknown active defects or high seismic risks;
- Slope of land <12 %;
- Proximity to existing power generation installations via renewable energy sources (Wind, solar, small hydropower plants);
- High voltage electricity lines;
- Proximity to natural gas pipelines;
- Proximity to fresh water or underground water sources;
- Distance from airports or military facilities > 20 km;
- Distance from the road or railways > 100 m;
- Distances from populated areas > 200 m.

Conclusions

Storing hydrogen in salt mines is an already well-known and secure technology.

The number of known incidents and accidents is very small compared to the large number of installations in operation and the enormous volume of stored gases.

It owed very strict rules and experience in storing energy underground in the form of gas, this technology has reached a very high level of safety.

There are a number of strict regulations that are in force in Europe regarding the planning, arrangement, construction and subsequent operation of gas deposits underground. Safety standards in Europe provide for the installation of a permanent system for monitoring working parameters in the cavern, which makes these technologies increasingly known to be functionally safe.

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