PROSPECTS AND OPPORTUNITIES FOR INCREASING THE CAPACITY FOR NATURAL GAS STORAGE IN UNDERGROUND GAS STORAGE FACILITIES IN THE REPUBLIC OF BULGARIA

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ABSTRACT. The article analyses the prospects and opportunities for establishing an underground gas hub on the territory of the Republic of Bulgaria in order to increase natural gas storage capacity. This is related to the well-developed gas transmission pipeline network, the numerous entry points for gas supplies to Bulgaria, and its transit to other countries. A summary classification of underground gas storage facilities is presented, depending on their place of creation. The basic principles for the construction of underground gas storage facilities in depleted hydrocarbon deposits, aquifers, and impermeable rocks are discussed. The distribution of underground gas storage in the European Union is analysed and prospective sites for underground gas storage are recommended.

Key words: natural gas, underground gas storage facility, gas hub

ПЕРСПЕКТИВИ И ВЪЗМОЖНОСТИ ЗА ПОВИШАВАНЕ НА КАПАЦИТЕТА ЗА СЪХРАНЯВАНЕ НА ПРИРОДЕН ГАЗ В ПОДЗЕМНИ ГАЗОХРАНИЛИЩА В РЕПУБЛИКА БЪЛГАРИЯ

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РЕЗЮМЕ. В доклада са анализирани перспективите и възможностите за създаване на подземен газов хъб на територията на Република България с цел повишаване на капацитета за съхраняване на природен газ. Това е свързано с добре развитата газопреносна мрежа, изградените множество входни точки за доставки на газ за България и неговото транзитиране за други държави. Представена е обобщена класификация на подземните газохранилища в зависимост от мястото на тяхното създаване. Разгледани са основните принципи за изграждане на подземни газови хранилища в изтощени залежи на въглеводороди, водоносни хоризонти и в непроницаеми скали. Анализирано е разпределението на подземните газохранилища в Европейския съюз и са предложени перспективни обекти за създаване на подземни газохранилища.

Ключови думи: природен газ , подземно газохранилище , газов хъб

Introduction

The establishment of an underground gas hub on the territory of the Republic of Bulgaria in order to increase natural gas storage capacity is an activity of strategic importance, which is related to ensuring the continuity of transportation and consumption of natural gas. This is related to compensating the seasonal irregularity in gas consumption, providing a strategic reserve of natural gas in case of supply disruptions, as well as to reserve the established gas transit system. The recent development of gas infrastructure in the region, including the Southern Gas Corridor projects, the implemented interconnections, and the available cross-border gas projects, justify the need to increase gas storage capacity. For this purpose, it is necessary to study and analyse the possibilities for the construction of an underground gas hub on the territory of the Republic of Bulgaria consisting of underground gas storage facilities.

Summary classification of underground gas storage facilities

A gas storage facility is a natural or artificially created technological complex in which natural gas is stored (Gerov, 2019).

Basically, gas reservoirs are classified according to their purpose and depending on the place of their creation (Gerov, 2019; Nikolov, 1993). According to the purpose, gas reservoirs are divided into:

- basic - to cover the seasonal (for several months) irregularity of gas consumption. They are characterised by relatively stabilised production regimes in the production period;
- peak - to ensure short-term (for several days) irregularity of gas consumption. They are characterised by significant variations of the daily productivity in the period of extraction;
- emergency - to form an emergency stock of gas used only in predetermined cases;

- strategic - used to secure a long-term supply of natural gas used in certain cases;
- complex - to ensure seasonal irregularity in gas consumption and to form an emergency or strategic gas reserve.

Depending on the place of establishment, gas storage facilities are divided into:

- underground gas storage in aquifers;
- underground gas reservoirs in depleted gas fields;
- gas condensate and oil reservoirs;
- underground gas reservoirs in rock salt.

Each type of storage is characterised by certain filtration, capacity parameters (porosity, permeability, m.h) and economic indicators (capital cost, operating cost, revenue, profit, internal rate of return, net present value, etc.), which determine the techno-economic efficiency (Mitev, 2006) of the establishment and operation of the reservoir. Most existing natural gas storage facilities are located in depleted natural gas or oil fields that are near consumption centers. Converting a field from a working field to a gas reservoir takes advantage of existing wells, gathering systems, and pipelines. Figure 1 shows the different types of underground gas storage.

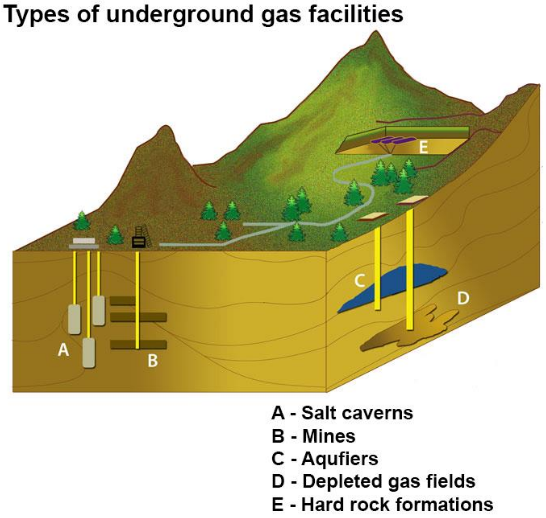

Fig. 1. Types of underground gas storage

The main parameters characterising the performance of underground storage facilities are: cycle, storage capacity (active and buffer gas volume, total volume), maximum storage throughput (when storage is full), minimum reservoir productivity (at the end of the production period), minimum and maximum formation and wellhead pressures, the quantity of production, monitoring, and control wells, and the required compressor station capacity to pump the gas.

Principles for the construction of underground gas storage facilities

The principles for the construction of underground gas storage include:

- Stage of design - design documents are drawn up (technological design for the creation of an underground gas storage facility and annual work projects);
- Multi-variant design - good established petroleum practice has proven that a process design for the creation of an underground gas storage facility should be multi-variant with different process parameters.

The steps in the construction of the Underground Gas Storage Facility are in the following sequence:

- Creation of a concept for an underground gas storage facility;
- Carrying out geological and exploratory work to investigate and analyse the possibility of creating gas reservoirs and expanding the existing ones;
- Technological design of underground gas storage;
- Environmental impact assessment and compatibility assessment;
- Technical design.

When creating a concept for creating an underground gas reservoir, it is appropriate to use neural networks (Boyadzhiev, 2023).

Distribution of underground gas storage in Europe

There are 27 Member Countries in the European Union and 19 of them have underground gas storage facilities. Europe's gas reservoirs are in aquifers, in depleted oil or gas deposits, in rock formations, or in salt formations. The total number of all underground gas storage facilities in the European Union is 160. Of these, 22 are in aquifers, 82 are in depleted oil or gas deposits, 2 are in rock formations, and 54 are in salt caverns. The country with the largest number of underground gas storage facilities is Germany with 60 UGS, while countries such as Belgium, Bulgaria, Greece, and Portugal have only 1 underground gas storage facility in operation. The data are shown in Table 1. Data on the amount of active gas in the Under Ground Gas Facilities of EU Member Countries are shown in Table 2.

Table 1. Number and type of UGS per EU Member Country

Country	Aquifer	Depleted deposit	Rock formations	Salt formations	TOTAL
Austria	-	9	-		9
Belgium	1	-	-	-	1
Bulgaria	-	1	-	-	1
Croatia	-	2	-	-	2
Czech Republic	1	7	1	-	9
Denmark	1	-	-	1	2
France	11	2	-	4	17
Germany	6	10	-	44	60
Greece	-	1	-	-	1
Hungary	-	5	-	-	5
Italy	-	21	-	-	21
Latvia	1	-	-	-	1
Netherlands	-	4	-	1	5
Poland	-	7	-	3	10
Portugal	-	-	-	1	1
Romania	-	7	-	-	7
Slovakia	-	3	-	-	3
Spain	1	3	-	-	4
Sweden	-	-	1	-	1
European Union	22	82	2	54	160

Table 2. Active gas volumes of UGFs of EU Member Countries

Country	Active gas volume, [bill. m^3]
Austria	9,942
Belgium	0,921
Bulgaria	0,500
Croatia	0,564
Czech Republic	1,585
Denmark	1,070
France	11,474
Germany	32,349
Greece	0,395
Hungary	7,127
Italy	5,174
Latvia	2,477
Netherlands	14,872
Poland	4,048
Portugal	0,406
Romania	4,643
Slovakia	4,817
Spain	3,505
Sweden	0,092

There are 6 countries that are not members of the European Union but are on the territory of the continent, they have a total of 36 underground gas reservoirs distributed as follows - 5 are in aquifers, 17 are in depleted oil or gas deposits, 0 are in rock formations, and 14 are in salt workings. Ukraine has the highest number with 13 underground gas reservoirs and Serbia with 1 UGS. The data are shown in Table 3.

Table 3. Number and type of UGS of non-EU countries

Country	Aquifer	Depleted deposit	Rock formations	Salt formation s	TOTA L
United Kingdom	-	2	-	10	12
Belarus	1	1	-	1	3
Russian Federation (European part)	2	-	-	1	3
Serbia	-	1	-	-	1
Turkey	-	2	-	2	4
Ukraine	2	11	-	-	13
non-EU	5	17	-	14	36

The total number of underground gas storage facilities in operation on the European continent is 196.

Characteristics of the established national gas transmission and transit network in the Republic of Bulgaria

The total length of the gas transmission system of *Bulgartransgaz EAD* in the Republic of Bulgaria is 3276 km. Along these pipelines, which are the National (blue) and Transit (red) pipelines shown in Figure 2, there are 11 compressor stations, with the compressors at the Ihtiman CS and Petrich CS being two-stage centrifugal compressors, and the compressors at the Chiren UGS being reciprocating compressors (www.bulgartransgaz.bg). The gas transmission system has 240 domestic exit points, 2 entry points from upstream facilities, 1 connection point to storage facilities, 8 cross-border entry-exit points, and 1 in-country interconnection point.

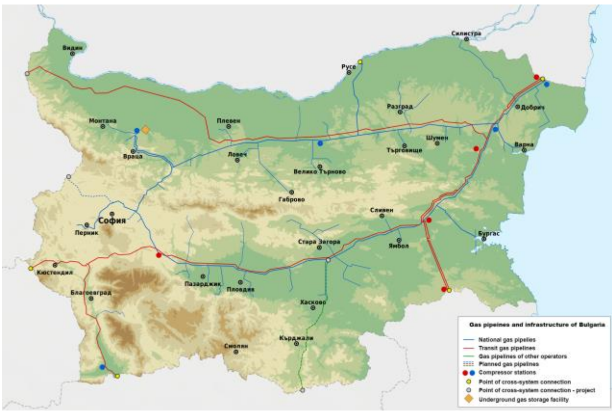

Fig. 2. Gas transmission network of the Republic of Bulgaria

The entry-exit points of the constructed national and transit gas transmission network are:

• **Negru Voda 1/Kardam** - Entry-exit point of interconnection between the networks of *Bulgartransgaz EAD* and *STNG TRANSGAZSA*, Romania, with a pipeline diameter of DN 1200 and throughput capacity of 2.3 bill.m^3/y

• **Negru Voda 2,3/Kardam** - Entry point of interconnection between the networks of *Bulgartransgaz EAD* and *STNG TRANSGAZ SA*, Romania, with a pipeline diameter of DN 1200 and throughput capacity of 7.0 bill.m^3/y

• **Kulata/Sidirokastro** - Entry-exit point of interconnection between the networks of *Bulgartransgaz EAD* and *DESFA SA*, Greece, with a pipeline diameter of DN 700 and throughput capacity of 1.7 bill.m^3/y

• **Ruse/Gyurgevo** - Entry-exit point of interconnection between the networks of *Bulgartransgaz EAD* and *STNG TRANSGAZ SA*, Romania, with a pipeline diameter of DN 500 and throughput capacity 0.13 bill.m^3/y

• **Strandja/Malkochlar** - Starting point of connection between the networks of *Bulgartransgaz EAD* and *BOTAS*, Turkey, with a pipeline diameter of DN 1000 and throughput capacity of 4.3 bill.m^3/y

• **Kyustendil/Zhidilovo** - Starting point of connection between the networks of *Bulgartransgaz EAD* and *NOMAGAS*, North Macedonia, with a pipeline diameter of DN 500 and flow capacity of 0.56 bill.m^3/y

• **Strandja 2/Malkochlar** - Entry point of connection between the networks of Bulgartransgaz EAD and TAGTAS, Turkey, with pipeline diameter DN 1000 and flow capacity 12.1 bill.m^3/y

• **Kireevo/Zaichar** - entry-exit point of connection between the networks of *Bulgartransgaz EAD* and *GASTRANS*, Serbia, with a pipeline diameter of DN 1200 and throughput capacity of 9.3 bill.m^3/y

• **Stara Zagora** - Entry-exit point of connection between the networks of *Bulgartransgaz EAD* and *ICGB*, Interconnector Greece - Bulgaria (ICGB new reverse gas interconnection between the gas transmission systems of Bulgaria and Greece). The length of the pipeline is 182 km, of which 151 km is on Bulgarian territory, with a pipeline diameter of DN 800. The capacity of the pipeline is up to 3 bill.m^3/y with the possibility of increase up to 5 bill.m^3/y by building a compressor station. The project has been successfully implemented by the joint investment company *IGB AD* with shareholders *BEH EAD* (50%) and the Greek *IGI Poseidon* investment company (50%).

• **Kalotina/Dimitrovgrad** - Entry-exit point of connection between the networks of *Bulgartransgaz EAD* and *SRBIJAGAS*, Serbia, with a pipeline diameter of DN 1200.

Prospective sites for expansion and establishment of new underground gas storage facilities

Expansion of the Chiren Underground Gas Storage

The Chiren underground gas storage facility was established in 1974. It was created in a depleted gas condensate field. The reservoir is carbonate, composed of fractured and cavernous limestones, dolomites, and low-porosity sandstones. The average open capacity is 1.7% and the fracture capacity is 0.1%. From the hydro-gas-dynamic studies of the wells, a permeability of 3 to 130 mD was determined (Gerov, 2019). The mode of operation of the reservoir is water-intensive. 42 wells have been drilled on the Chiren gas-bearing structure. During the period of exploitation of the Chiren gas condensate field and subsequently during the periods of exploitation of the Chiren underground gas reservoir, the drilled wells were used for different purposes. Depending on the current condition and purpose, the drilling stock is divided into the following groups: exploitation-pressure wells - 24, piezometric/observation wells - 17, special-purpose wells – 1, and liquidated wells - 4.

A compressor station with a total installed power output of 10 MW and other technological facilities necessary to ensure the injection, production, and quality of the stored gas have been built at the Chiren underground gas storage facility.

The maximum daily production rate from all wells is 3.82 mln.m^3/d (when the storage is completely filled), and the minimum daily flow rate for all wells is 0.5 mln. m^3/d (at the end of the production period). The maximum daily injection flow is 3.2 mln.m^3/d, and the minimum daily flow rate at injection is 0.5 mln. m^3/d. Currently the active gas volume is 550 mln. m^3.

A project to expand the Chiren underground gas storage facility is underway. The project foresees a phased increase in the capacity of Bulgaria's only gas storage facility to achieve higher volumes of stored gas and higher average daily production and injection rates (www.bulgartransgaz.bg). The project will increase the active gas volume to 1 bill.m^3 and an increase in the maximum daily flow rate when producing from all wells to 10 mln.m^3/d, as well as an increase in the maximum daily flow rate when injecting to 3.8 mln.m^3/d. For this purpose, the formation pressure will be gradually increased to 150 bar. The expansion will be accomplished by drilling 10 new production/injection wells and 3 new observation wells, as well as constructing the necessary surface facilities (flowlines, individual separators, compressor station upgrades) and infrastructure.

For the implementation of the storage extension, the following exploration activities have been successfully carried out, both in terms of volume and quality: Geomechanical simulation of the Chiren reservoir, land gas analysis on the Chiren structure area, and 3D seismic surveys on the Chiren structure area.

Sites for new underground gas storage facilities

The Galata gas field

The possibility of transforming the Galata gas field into an underground gas storage facility should be considered in the context of a clarified concept of the need for new gas storage facilities. This concept should be developed on the basis of a decision on which of the following tasks is a priority:

- compensation of seasonal irregularities in gas consumption (seasonal gas storage);
- full or partial provision for a certain period of time of the gas consumption in case of emergency situations in the gas transmission system or in other exceptional circumstances (emergency gas storage);
- provision of a strategic reserve (back-up gas storage);
- redundancy of the gas transit system (redundant storage).

An underground gas reservoir, with the existing characteristics and infrastructure, can only be built if there is convincing evidence of favorable geological, technical, technological, and economic conditions. Otherwise, the investment risk is significant.

In case of unfavorable geological, technical, technological, and economic preconditions for the establishment of underground storage of natural gas, it is appropriate to investigate and analyse the possibility of underground storage of CO_2.

The Balgarevo gas field

Due to its location, the Balgarevo gas field is 60 km away from the main gas pipeline, which is a suitable factor for its transformation into an underground gas facility. The gas regime of the field (Gerov, Georgiev, 2007), the shallow depth, and isolation of the reservoir allow the use of the field as a gas reservoir after 3D seismic surveys and data processing, as well as processing of data from the hydro-gas-dynamic surveys conducted in the wells. The existing well stock is obsolete and new production wells need to be drilled and new surface equipment constructed. The bottom hole zone of new wells must be filtered to limit the export of mechanical impurities from the formation and the possibility of operating wells with a depression greater than 0.15 MPa. If the Balgarevo field is transformed into a UGSF, it is necessary to construct a 60 km-long transmission pipeline diversion.

The total storage capacity is set at 160 mln.m^3 gas, of which 80 mln.m^3 is the active storage volume and 80 mln.m^3 is the buffer storage volume. The estimated maximum daily extraction flow is 0.83 mln.m^3/d and the minimum daily flow is 0.5 mln.m^3/d.

The Mirovo and the Monastery salt deposits

Prospects for natural gas storage exist in the salt bodies associated with the Mirovo salt field.

The Manastir salt field is strategically located 5 km from the gas main pipeline. At this stage, there is insufficient geological and geophysical information available on the deposit. The average insoluble residue in salt is 18.2 %. The estimated capacity of the salt chamber is 162 mln.m^3, where the active volume is 114 mln.m^3 and the buffer volume is 48 mln.m^3. The estimated maximum daily extraction is 3.29 mln.m^3/d, and the maximum daily injection flow is 4 mln.m^3/d. The maximum wellhead pressure in the pumping cycle is 10.7 MPa, and the minimum wellhead pressure is 3.12 MPa. Three stages of compression are required to compress the gas.

The Gorsko Slivovo aquifer structure

The Gorsko Slivovo aquifer structure represents an aquifer complex, attached to the carbonate overlays of the malm-valanzhina (Zaneva and Hristov, 2019).

The estimated cumulative storage capacity is estimated at 650 mln.m^3 gas, of which 300 mln.m^3 is the active gas volume in the storage facility and 350 mln.m^3 is the buffer gas volume. The expected maximum daily extraction is 10 mln.m^3/d.

Conclusion

The analysis identified the prospects and opportunities for establishing an underground gas hub on the territory of the Republic of Bulgaria in order to increase the natural gas storage capacity by expanding the existing Chiren underground gas reservoir and developing a concept for exploration of the considered depleted gas fields, aquifer structure, and salt deposits.

The establishment of an underground gas hub on the territory of the Republic of Bulgaria is of strategic importance, which is related to ensuring the continuity of transportation and consumption of natural gas.

The establishment of new underground gas storage facilities, from the commencement of exploration activities to their entry into regular operation, can be carried out over a period of 5 years if funding is secured.

References

Boyadjiev, M. 2023. *Neural networks in the gas industry*. "Print Factor", Sofia (in Bulgarian).

Gerov, L., L. Georgiev. 2007. Analysis of methods for determining the regime of gas reservoirs in the initial stage of development*, Yearbook of the Mining and Geological University "St. Ivan Rilski", Sofia Vol.50*, St. I, Geology and Geophysics, 2007, pp 153-157.

Gerov, L. 2019. *Natural gas production and storage*. UMG "St. Ivan Rilski", Sofia, 297 pp. (in Bulgarian).

Karadjov, M. 2021. Problems, opportunities and solutions for household gas supply in Bulgaria*. Mining and Geology –, issue 2*, pp. 33-36 (in Bulgarian).

Mitev, V. 2006. Indicators for evaluation of investment projects for the extraction of mineral raw materials*. Sp. "Mining and Geology", no. 5*, 2006, pp. 22-23. ISBN 0861-5713 (in Bulgarian).

Nikolov, G. 1993. *Transport and storage of oil and gas.* UMG "St. Ivan Rilski", Sofia (in Bulgarian).

Popov, A., E. Kishkin, R. Ivanov, L. Gerov, G. Nikolov.. 1995. *Bugarias role in the supply of natural gas to the Balkan countries.* Balkan Black Gas Association, pp 14-16.

Zaneva, E., N. Hristov. 2019. Geological conditions for the construction of an artificial gas accumulation "Gorsko Slivovo" in Northern Bulgaria. *Mining and Geology, issue 3*, pp. 42-49 (in Bulgarian).