

THE IMPORTANCE OF UNDERGROUND STORAGE ON THE WORLD MARKET AND TENDENCIES OF UNDERGROUND GAS STORAGE DEVELOPMENT

O. T. Chernova

ІФНТУНГ; 76019, м. Івано-Франківськ, вул. Карпатська, 15, тел. (03422) 727138,

e-mail: m - o k s a n a - t @ u k r . n e t

Коротко охарактеризовано мережу підземних сховищ світу, приведено характеристики діяльності та сучасний стан підземних сховищ газу США, країн Західної Європи, Центральної Європи та України.

Сформульовано питання і основні вимоги до розвитку підземного зберігання, а також пропонуються нові технологічні рішення, спрямовані на підвищення рівня їх експлуатації. Реконструкція і модернізація підземних сховищ, підвищення їх продуктивності значно посилює енергетичну безпеку і утворюють незалежність країни, а також забезпечить надійність поставок газу.

Ключові слова: мережа підземних сховищ, активний об'єм газу, пікові газосховища, газозабезпечення.

Кратко охарактеризовано сети подземных хранилищ мира, проанализированы деятельность и современное состояние подземных хранилищ газа США, стран Западной Европы, Центральной Европы и Украины.

Сформулированы вопросы и основные требования к развитию подземного хранения, а также предлагаются новые технологические решения, направленные на повышение уровня их эксплуатации. Реконструкция и модернизация подземных хранилищ, повышения их производительности значительно усилят энергетическую безопасность и утвердит зависимость страны, а также обеспечит надежность поставок газа.

Ключевые слова: сеть подземных хранилищ, активный объем газа, пиковые газохранилища, газоснабжения.

Short characteristics of the net of world's underground storages was set out, the activity and modern state of underground gas storages in the USA, countries of Western Europe, central Europe, and Ukraine was analyzed.

The questions and main requests for the development of underground storage, and also new technological solutions directed to raise the level of their exploitation were formed. Reconstruction and modernization of underground storages, rise of their productivity will considerably increase energy safety and dependability of the country and will also provide the reliability of gas supply.

Key words: network of underground storages, active gas volume, peak gas storages, gas supply.

The underground shelters have a great importance on the market of natural gas in the whole world. Nevertheless gas storages are disposed rather disproportionately around the territory.

According to the data of US Geological Survey at 01.01.10 there are 642 UGS with general active capacity of 333 billion m³ in the world, that corresponds to 10,8 % of world gas consumption.

At the beginning of the 90th the liberalization of gas market began which led to the change of the situation of the underground storages usage. To secure free competition on the market capacities for gas storage were taken out from the management of gas corporations and reorganized into independent commercial entities which are obliged to provide gas storage for all comers on suitable basis.

The changes led UGS to be used not only for providing uninterrupted supplies of gas in the cold period of the year but for profit-making. Gas was injected into underground storages when its cost was minimum, and it was pumped out and sold at the moment of appreciation of its cost. At that period the urgency of peak gas storages in the world which had capacity to supply rapid giving out the product, increased sharply. That is why the peak of constructing the gas storages in salts in the USA and Europe took place at last decades.

The urgency of the given problem partly decreased in connection with extracting of schistose gas in the USA and at the appearance of numerous LNG. Also the corporation Shell and E.On. have lately developed the projects of "virtual" gas storages. In the judgment of specialists of these companies European UGS of different types should be united into network and on the basis of common capacities propose the contracts for gas storage. This factor will allow deriving an income for UGS and reducing the risks of gas trends.

The question of the constructing and exploitation of underground gas storages has been actual during many years. The founder of the network of UGS of Ukraine and the drafter of the project's documents for its construction is UkrNDIgas. This is the only organization in Ukraine, which has been solving the problems connected with underground storage of gas for 40 years [1]. So in 1968-1970 the experts of the institute of gas started the long-lived study of needs and structure of power supply of main gas users, such as Kyiv, Kharkiv, Donetsk, Odesa, Lviv and others. A group of scientists under the supervision A.V. Baranov and S.A.Pinchuk offered the methods of the prognostication of compensation of seasonal disproportionality of usage with the aim of study of the capacity of storage and productivity of UGS [2, 3], and argumentation of

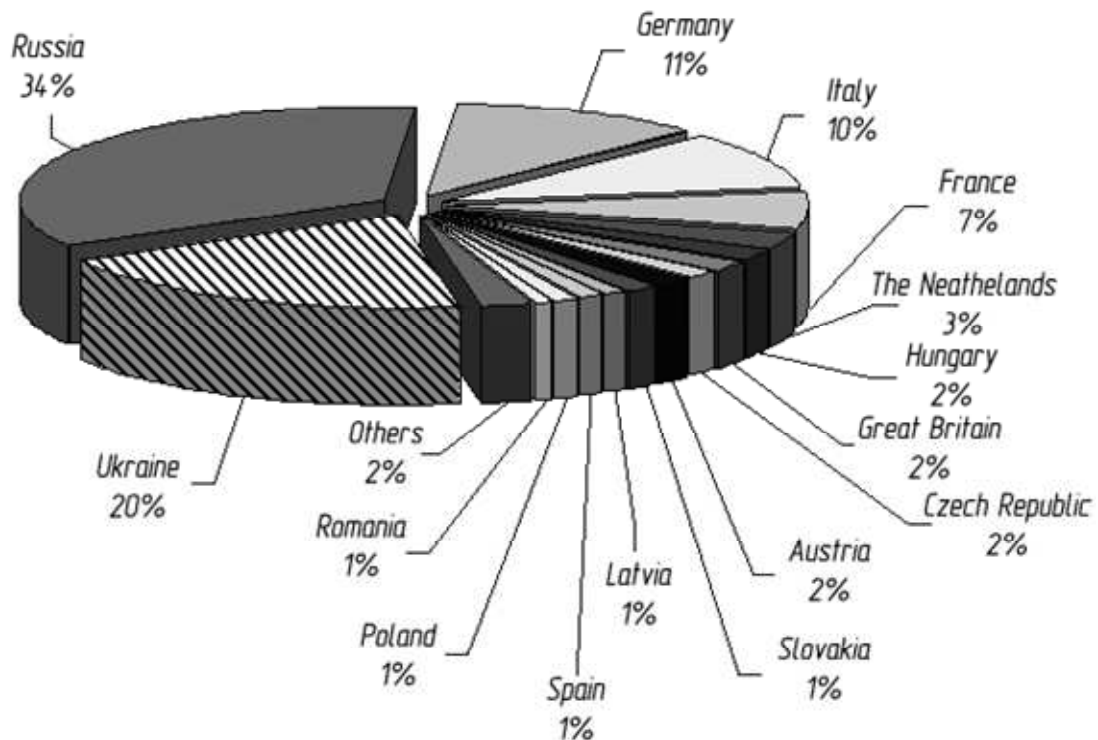


Figure 1 – The share of active holding capacity of UGS in the European countries

the main characteristics of the UGS [4]. The given works are directed to constructing and exploitation of the underground storages. For supervisory control of the UGS, the control services were offered the supply of information about the possibility of taking away at any time. The presence of gas in the stratum is shown with the help of indicated curve [5].

A lot of research works mainly connected with the Carpathian complex of underground storage belong to Gimer R.F. At the same time Savkiv B.P. [12], Andrijishin M.P. [11] and other scientists worked at separate questions of the development of the network of underground gas storage. The results of their works were used at the development of amendments of separate projects at the designing and constructing of separate underground storages.

The questions of development of underground storage in Russian Federation are paid attention in the works of B.V.Budzulyak [7], A.E. Arutyunov [8]. Successful development of underground gas storages in Ukraine has assisted to close cooperation of leading scientists of Ukraine and Russia. It is worth notice Russian scientists such as S.M. Buzinov, Y.L. Gusev, Y.K. Ignatenko who worked at the scientific and technological questions of projecting and constructing of underground storages of Russia and Ukraine.

The definition of underground storages, their significance and character of work are given in the appliance "Handbook of natural gas engineering" edited by the professor of Michigan University D.L.Kanz [6]. The characteristics of the underground storages of the USA, the value of active and buffer volume of gas in this country are characterized in the works [9, 13].

In the most storages the active and buffer volume of gas are approximately equal, that is their correlation of active gas to the buffer is 1:1. In 1994 the share of buffer gas in the USA was 58 % [13]. In the underground storages of Ukraine the share of buffer gas is 51 % and less. That is why the question of modernization of world underground storages is actual.

For 2003 in the countries of Eastern Europe and former Soviet Union it was concentrated about 40 % of UGS. Approximately the same amount falls on Canada and the USA. Nearly 20 % of UGS is situated in Western Europe and only some storages are situated in the countries of Eastern Asia and in Near East with the total capacity of 3 billion m³. Such correlation is illustrated by the necessity of disposition of underground storages in the places where there are seasonal fluctuations in capacities of natural gas usage (Fig. 1).

The network of the underground storages is planned to be expanded by Russia, Turkey, Iran, Australia and China. Prognostication of the state of development of underground storages of Europe and the USA testifies to the fact that only some projects will be carried out as it has been prognosticated before. However, the world's industry in the future decades all the same should do steps forward as the safety of world's gas market, its resistance to different crises and irregularities depend in mainly on the state of underground storages of the world.

On 2012 more than a half of the backup storage of gas falls on three countries: the USA, Russia and Ukraine. For last decades the amount of underground storages and their total capacity has not practically changed. From 2000 to 2012 the total capacity of world's UGS has increased only to

Table 1 – Stage-by-stage building of underground gas storage in the USA

Years	Amount of storages	Maximum productivity, billion m ³ 24 hours	Capacity of active gas, billion m ³	Maximum capacity of gas storages, billion m ³
1970	325	-	-	148,4
1975	376	1,03	-	190,4
1980	401	1,09	161,0	214,8
1985	419	1,5	167,0	222,5
2005	417	2,2	110,5	220,0
2014	417	2,2	110,7	223,0

10 %. The construction of new objects has been stopped in the world. In some countries it was substantiated by crisis situation in the world, but in others (the USA and Europe) by gas market liberalization for last 10-15 years.

At present day the largest amount of UGS belongs to the USA. In these underground storages about 115 billion m³ of gas with maximum productivity of 2,4 billion m³ a day could be stored. This parameter is proved by the specific character of gas market and a great number of the organizations involved [13].

Stimulus of the development of UGS in the USA became the process of correction of gas market. By this the cancellation of the control of industrial prices for gas was expected. It allowed setting tariffs on gas storage with the consideration of local and seasonal differences in commodity price for gas, and inserting the mechanism of independent purchasing of gas by consumers and conclusion of separate treaties with transport companies about transportation and storage of gas with the payment of services by tariffs.

The first underground gas storage in the USA was created in 1915-1916 with total capacity 62 billion m³ in New York State (Zoar-Erie). The problem of gas storage in the given country was paid a great attention and by the end of 1983 the total amount of UGS had reached 419 with the total storage capacity of 167 billion m³ and daily productivity of 1,5 billion m³. From 1970 to 1983 the amount of underground gas storages increased to 84 units, 13 underground storages among them were constructed in aquiferous stratum.

The characteristic feature of underground gas storage in the USA is a big reserve of active volume of gas [13]. With the general usage of gas of 478,7 billion m³ in 1983, the maximum volume of storage was 167 billion m³ at the total gas capacity in UGS of 222,5 billion m³.

The volumes of underground gas storage in the USA, reached at the beginning of 80-s, in what follows are at the same level. The changes are in the direction of increasing not volumes of storage but productivity of UGS. Thus, for 2005 in the USA there are 417 UGS. 348 from them were created in overworked gas and oil deposits (occurrences), 40 were built in aquiferous stratum, 27 in salt cavities and 2 in mines. Thereby, the total amount of UGS even reduced in comparison with 1983, at the same time maximum productivity increased from 1,5 to 2,2 billion m³. Stage-by-stage.

Building of underground storages in the USA is shown in table 1 [9].

As you can see in table 1, during 1970-1985 the amount of underground storages in the USA was increasing and in 2005 it reduced by two units. It is connected with consolidation of storages. At the same time, during the given period maximum productivity and maximum volume of gas storage increased practically in two times [14].

As to the building of new underground storages in the USA, the situation doubled. Constructed during many years storages with big reserve could not satisfy the capacity of gas that needs to be stored. It is argued by the appearance of schistous gas at the gas market. That is why the decision was made to cut down the mining of gas as there was no place to its storage. At the other hand the price for gas in the America is so high that it is not profitable to pay big sum of money for its storage. It means that the building of new UGS at the present time has very long term of recoupment [6].

That is why during the last years the questions and basic requirements of the development of the USA underground storage were formulated:

- creating the possibility of increasing of twenty-four-hour gas mining from the underground storages by increasing of wells' amount and drilling of newest highly discharged wells;
- extension of UGS nets at the cost of creating new ones in overworked deposits (occurrences) or salt cavities;
- creating the opportunities to use of compressor stations with maximum power.

The peak UGS today make less than 10 % from the total capacity of world's capacities of underground storage. Most of them are situated in the USA where active volume, about 30 of UGS, located in salt, make 8 billion m³. In Germany we can count 19 similar storages with an active capacity about 7 billion m³ for 2010. In general in this country the portion of reserved gas, located in peak storages is the highest in the world and makes more than 25 %.

In the countries of Western Europe the underground storage was developing rapidly. And for 2005 in these countries more than 80 UGS were operating. Germany owns the biggest amount of storages - 42, France has 15, there are 10 in Italy, and 5 in Australia. Hereby Germany, France and Italy own 75 % of capacities of gas storages if Western Europe. Analyzing the given countries we

Table 2 – Parameters of underground storage of Western European countries

Country	Number of UGS	Volume of gas, million cubic meters		Maximum daily productivity, million cubic meters a day
		total	active	
Germany	42	27,5	19,772	437,9
Italy	10	27,8	17,300	198,8
France	15	23,1	11,633	182,5
Netherlands	3	20,0	4,750	196,0
Great Britain	4	10,2	3,267	54,8
Austria	5	6,4	2,980	29,4
Spain	2	3,4	1,990	10,7
Denmark	2	1,15	0,815	25,2
Belgium	2	1,09	0,650	9,6

can say that underground storage of Germany was developing stage-by-stage. Storages of gas were built there in aquiferous structures on different depths and in salt excavations. The active volume of these storages now is 19,77 billion m³, and twenty-four-hour productivity is 437,9 m.m³/day. During new millennium 7 new UGS were in Germany were brought into action in Germany and also the projects for creating of two more new storages in porous stratum and twelve in cavities for additional volume of gas were developed. Theoretically all active volume from German UGS can be taken away for 45 days.

France has similar parameters of underground storage. There are 15 UGS located across the country, 12 of them are created in water-bearing layers, and three in layers of salt caverns at a depth of 1400 m. The active volume of all storages is more than 11 billion cubic meters, and the maximum sampling of gas is 182,5 million cubic meters per day. It is also known that it is possible to select all active gas from these storages in 63 days.

There are 10 underground storages in Italy. They are located in depleted fields and have an active volume of 17,3 billion cubic meters of gas. The selection of all active gas can be conducted within 87 days under condition of a maximum daily productivity – 198,8 million cubic meters.

It should be noted that other Western European countries have a much smaller amount of storages (from five to two), and the volume of these storages is up to 5 billion cubic meters. Parameters of underground storage of Western Europe (on 2005) are shown in table 2 [9].

The main issue of UGS development in Europe is to increase the value of the active gas volume. The solution of this problem will allow using natural gas effectively, as it will reduce the cost of its storage. Given problems are justified by the technology of producing of underground storages. European storages were constructed with a strategic purpose. In the present the parameters of their work are considered imperfect. Therefore, at present the construction of new underground storages is being discussed in five projects in Western Europe.

In the countries of Central Europe the volume of underground gas storage is slightly less. However, it should be noted that in Poland back in

1954, the scientific research on underground storage had been started. On 2000 there are 6 active gas storages and 5 - at the design stage in this country. Also the fact that Europe and the former Soviet Union exchanged experience in designing and operation of underground gas storage should be noted.

The most powerful industrial and scientific country in the field of underground gas storage is considered to be Russian Federation [7]. It ranks the second place in terms of the volume of underground storages. After the collapse of the Soviet Union its complex consisted of 21 UGS with an active volume of 40 billion cubic meters of gas and maximum daily capacity - 300 million cubic meters per day.

Nowadays there are 25 UGS (more than 66 billion cubic meters) located in Russia, with a maximum capacity of more than 620 million cubic meters per day. 80 % of the total storage capacity is built in overworked oil and gas deposits and less than 20 % in aquifers. In addition, Russia has the largest UGS in the world: North Stavropol and Kasymovskyy. North Stavropol UGS is located in depleted gas field (according to Gazprom in this underground storage can be stored up to 37,8 billion cubic meters of gas), active volume of this storage is 15 billion cubic meters (after expansion is planned 28 billion cubic meters). Kasymovskyy UGS is located in water-bearing layer with an active volume of 7,5 billion cubic meters of gas. The volume of the commercial gas in the gas storages has reached 63 billion cubic meters, and the maximum daily capacity - 600 million cubic meters. The selection of all active gas from UGS is theoretically made within 160 days.

Russia attaches great importance to the issues related to the underground storage. The research and development, updating and modernization are conducted [8]. The solution of set problems will allow increasing till 2030 the volume of active gas to 110 billion cubic meters. The development of underground gas storage of gas in Russia is formed in the following requirements:

- creation of peak gas storage in simple layers, rock salt, and creating systems for liquefaction, storage and regasification of liquefied natural gas;
- reconstruction and upgrading of equipment of UGS and installation automatic devices;

- solving the questions of increasing of productivity of underground storages and cutting down the period of selection by constructing of highly debit wells, creating the possibilities of productivity increasing of operating wells, changing of technology of gathering and draining of gas, increasing the effectiveness of UGS management;
- increasing flexibility of work of storages by changing the gas injection processes in winter and introducing new modes of injection and sampling;
- studying of alternative technologies of gas storage.

The problem of underground gas storage in Ukraine emerged due to the need of gas supply of major centers and capital cities. Finding favorable structures for the creation of an underground storage for Kyiv started back in 1955. As the result of geological research, Olyshivska and Chervonopartyzanska structures were selected [1].

Ukraine in the early 60s was the main gas-extraction region of the former Soviet Union. With the help of Ukrainian underground storages of natural gas were satisfied the needs of domestic consumers of natural gas of Moldova, Russia, Belarus, Lithuania and Latvia and implemented export to Poland, and from 1967 and 1968 in Czechoslovakia and Australia. But even then because of the lack of Ukrainian own sufficient resources in the winter period big cities (Moscow, Leningrad, Kyiv, Kharkiv and Lviv) felt inadequate gas supply. Therefore, it was decided to create underground gas storages in aquiferous structures near these cities.

The network of underground gas storages in Ukraine, which was created during the last 50 years consisted of 13 underground storages created in simple layers (two - based on water-bearing structures and 11 - at the exhausted gas fields). It ranks the second place in Europe in terms of total volume of underground gas storage and one of the highest on the list for a total daily capacity. The total equipped active capacity of the network is 32,0 billion m³; its performance at the beginning of sampling season may be about 300,0 million m³ [10].

Exceptionally favorable geographical location of Ukraine at the crossroads of main existing transcontinental and interstate pipelines makes it a kind of "gas bridge" between these regions.

With the help of the Ukrainian gas transport system about 90 % of Russian gas exports is carried or over a quarter of the needs of European countries. In terms of gas transit through its territory our country surely ranks the first place in the world. Through our gas transportation system annually passes over 100 billion cubic meters of gas to 18 countries in Central, Eastern and Southern Europe.

Ukraine is one of the largest consumers of natural gas, ranking on this indicator sixth place in the world and fourth in Europe after Russia, UK and Germany, far ahead of such big countries like Italy and France [2].

It must also be noted that all UGS of Ukraine, namely more than a half of existing, have more than 2 billion cubic meters of an active gas each.

Ukrainian underground gas storage network is a dynamic system that is closely related to the technological element of a large gas transportation system of Ukraine and also has great international significance. But to the future successful and high-quality functioning of Ukrainian network of underground storage, continuous improvement, upgrade and modernization is needed.

The modernization of gas transit system of Ukraine was raised over the past decade. It is viewed through different points of view. According to the words of the Minister of Energy and Coal Industry of Ukraine, Eduard Stavisky, our country plans to increase the volume of its underground storages (UGS) to 50 billion cubic meters. It is possible, according to his words, as Ukraine has geological opportunities to build gas storages in the central regions, in particular Kharkiv and Poltava region. The minister believes that it is possible to build there UGS with the capacity from 10 to 20 billion cubic meters of gas. However, in terms of commerce UGS construction requires large costs, difficulties in obtaining the necessary permits and long payback period.

More detailed and undertaken is the question of reconstruction of existing gas storages. To perform the tasks, Ukraine began launching the reconstruction of the main gas pipeline Urengoy-Pomary-Uzhhorod. It is believed that during the seven years (according to the Ministry of Energy and Coal) reconstruction will take place throughout Ukrainian GTS.

To date, according to the JSC "Ukrtransgas" Ukrainian gas pipeline length is 38,6 thousand km, including 22,2 thousand km of gas mains (of which 14 000 km with the diameter 1020-1420 mm) and 16,4 thousand km of gas pipeline branches. The capacity at the input is 285,7 billion cubic meters per year, and at the output of 178 billion cubic meters per year (including 146 billion cubic meters per year in European countries).

Also the gas transportation system of Ukrtransgas includes 72 (110) compressor stations (shops) with total capacity of 5442,9 MW, 702 GPA and 12 underground gas storages (UGS) with a total active capacity of 31 billion cubic meters and infrastructure that supports the functioning of the system.

It should be noted that in the period of 1980-1990 the rate of development of underground storage had no equals in the world: the total storage capacity has been increased to 11, and active storage to 18 times [10].

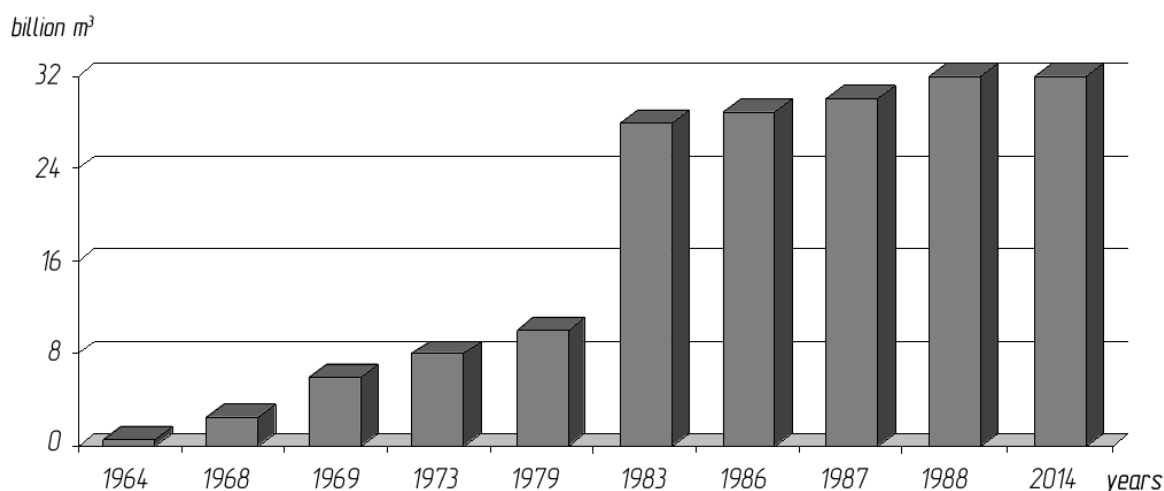
Dynamics of volumes of gas in UGS are shown in table 3, and the dynamics of increase of the active volume of gas in underground storages of Ukraine during the period of their construction and operation are shown in Fig. 2.

Growth rates indicate that our country has a strong system of gas transportation and storage which provides gas supply to domestic and international consumers (about 75 billion cubic meters per year).

Ukraine geographic location allows the supply of natural gas by GTS from gas producing regions of Russia and Central Asia to European countries,

Table 3 - Dynamics of volumes of gas in UGS, billion cubic meters

Year	The total volume of gas injection	Including		The volume of gas injection during the season	Gas selected during the season
		active gas	buffer gas		
1976	3,4	1,6	1,8	-	1,4
1980	4,4	1,8	2,6	2,0	2,1
1985	23,4	10,8	12,6	12,6	7,9
1990	49,4	31,6	18,2	18,0	21,2
2014	49,4	31,6	18,2	18,0	21,2


Figure 2 – Dynamics of increasing of active volume of as in UGS, billion cubic meters

fulfilling the contractual obligations of gas transit [7]. This enables Ukraine to play a major role in the international system of gas transportation and helps to accelerate its integration into the European and world economy. Transit of gas to 19 European countries in recent decades has grown steadily and in 2004-2007 years stabilized at the level of 110-120 billion cubic meters, that is a quarter of the volume of gas consumption by these countries.

Since 1991 Naftogaz of Ukraine annually highlights the volume of gas transportation on the territory of Ukraine. Thus, in 2005 the balance of gas consumption during transportation by Ukrainian GTS was 1,06 billion cubic meters (0,5 % of the total amount, received by the country). We also know that during the transit of Russian gas to Europe Ukrtransgas spends about 7 billion cubic meters per year (process gas). For the country safe and high-quality delivery of the product should be a priority.

Another negative factor is the fact that most of the pipelines were built in the 60-70's of last century. Therefore, the technical condition and operational efficiency of GTS of Ukraine do not meet modern requirements, because:

- over 29 % of Ukrainian gas pipelines have already worked their amortization period;
- more than 60 % of the communications of the gas transport system (GTS) were in operation from 10 to 33 years;
- every third unit of gas pumping has worked out its service life and needs reconstruction;

- 11,6 thousand km gas networks (about 7 %) and 4,9 thousand gas control points (about 14 %) are operated over the given period of depreciation.

The necessity of modernization and technological upgrading of objects of gas transportation system of Ukraine is determined by:

- moral and physical deterioration of technological equipment, in case, if moral and physical deterioration of equipment prevents from performing its basic functions;
- negative results of diagnostic and inspection of technological and subsidiary equipment;
- impossibility of continuing the resource of exploitation of technological equipment provided by the manufacturer;
- decline in the reliability and efficiency of gas transport;
- construction of new electricity generation capacity in the area of the gas transportation objects or appearance of excess electricity, enough for the functioning of the GTS object in the power system of the region (if the excess electricity is enough for the functioning of the GTS object);
- the ability to improve reliability and efficiency of equipment on domestic enterprises at minimal cost.

The question of modernization of the gas transit system is described in various literatures. But the reliability of transit of gas supply and gas supply of domestic consumers cannot be performed regularly without the complex of underground gas storages. The main part of them (up to 80 % of volume) is located in the western region of Ukraine

in the area of the final sections of the main Ukrainian export gas pipelines: "Union", "Progress", "Urengoy-Pomary-Uzhorod". That is why it is also important to highlight the necessity of modernization of underground gas storages.

According to this we can conclude that in recent decades the volume of underground gas storage remains virtually unchanged. Changes occur in the direction of increasing its effectiveness and productivity. The main directions of development are related to the continuous improvement, upgrading and modernization.

There are several reasons of awakening of interest in the construction and renovation of UGS. For European countries the main role has been played by the crucial misunderstanding in gas question in recent years. As it turned out, the supply of LNG is unable to compensate possible disruptions in the transportation of Russian gas or abnormal cold, leading to a sharp increase in demand for gas in Russia itself.

In this respect, underground gas storages are considered an essential element of the European gas security, as they complete the qualitative operation of the gas transportation system and provide gas flow.

Requests and Recommendations

Therefore, in recent years, global trends in underground gas storage were formed in such claims and issues:

- construction of high-performance wells (drilling horizontal wells, the use of new technologies for their installation, that leads to the increase of daily sampling of gas from UGS);

- increasing the number of wells due to the construction of new ones, increasing the diameters of lift columns, ensure the tightness by updating their installation methods.

The result will be the productivity of existing wells:

- changing and improving of technologies of sampling and drying gas, maximum possible utilization of capacity of compressor stations after their modernization.

But still the main problem of underground gas storage is the ability to increase the value of active volume of gas in the existing underground storages.

It also provides measures to bring the conditions of operation and maintenance of wells to the modern world requirements through introducing new technologies, drilling new horizontal wells and horizontal shafts in existing wells. Also an important issue is the implementation of information management systems based on modern software and hardware, controlled mechanisms of new equipment, telemetry control systems of technological equipment and operation of wells for the effective management of UGS in general and implementation of optimal modes of operation of wells.

Mentioned problems should be solved by combining the work of scientists and technologists. Their solution will lead to:

- the opportunity to reduce operational costs;
- the improvement of the environmental sustainability of UGS;
- the reduction of gas storage tariff;
- the opportunities for the development and implementation of alternative technologies of gas storage.

The economic crisis and the credit squeeze also play a negative value. For instance, in the end of 2012 major projects in Great Britain were closed. The lack of funds is the reason of defective repairs at the underground storages and untimely replacements of equipment for newest one.

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*Рекомендована до друку
професором **Грудзом В.Я.**
(ІФНТУНГ, м. Івано-Франківськ)
д-ром техн. наук **Говдяком Р.М.**
(ТЗОВ «Інжинірингова компанія
“Машекспорт”», м. Київ)*