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WAYS OF INCREASING NATURAL GAS STORAGE CAPACITY IN UNDERGROUND GAS STORAGES IN THE CZECH REPUBLIC

Abstract: Natural gas fields are usually located far away from the end users and industrially developed countries, where the gas demand is highest. In such cases, natural gas is transported from the production site to the receiver mainly with gas pipelines. Such pipelines may transmit a definite volume of natural gas. Most of the time gas transport is stable in time, unless the demand changes, e.g. in winter or in the case of pipeline failure. In such a case the pipeline system cannot cover the increased demand and supply sufficient amounts of gas. One of the ways to solve the problem of varying demand and limited potential as far as gas transmission over long distances is concerned, are underground gas storages, thanks to which the operational gas deliveries can be regulated, i.e. it can be stored in periods of lower demand and used in the high demand situations. This safety buffer provides the stability and reliability of the entire natural gas distribution system. The methods of increasing the natural gas storage capacity of UGS were discussed in this paper with special emphasis on the primary and secondary tightness of geological structures hosting UGS. Authors also analyzed how laboratory tests conducted at VŠB-TU Ostrava can be broadened to verify the possibilities of increasing natural gas storing capacity, depending of the geological horizons and structures in which the UGS is located.

Keywords: natural gas, storage of natural gas, ungergroung storages for natural gas, capacity of underground gas storage, geological structures used for gas storage

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1. INTRODUCTION

Underground gas storages (UGS) are an important part of natural gas transmission systems in all industrially developed countries [1, 2].

Initially gas storages were a novelty used mainly for seasonal compensation of natural gas consumption. Presently they play an important role in the gas transmission and distribution systems. This is mainly connected with the increase of gas consumption and the need of realizing gas transmission over long distances. Gas transmission systems associated with UGS allow for using the maximal annual transmission capacity.

Achieving such a high value of natural gas transmission has a positive effect on the exploited gas fields. Underground gas storages used as intermediate buffers increase the degree to which production wells are used; the production is maintained on a constant level in time, and this in turn, has a positive effect on the use of reservoir energy [3, 4].

At an early stage of their development, UGS were mainly located in old hydrocarbon deposits, though the availability of such deposits is limited; in a number of cases they are far away from places where natural gas consumption is highest [5–8]. In the places, where the accessibility of old deposits is limited, cavern reservoirs or aquifers were used [9, 3, 10].

The total volume of gas in an underground gas storage (reservoir horizons – storage horizons) can be divided into two basic parts, i.e. active and passive. The passive part is also referred to as a buffer or a cushion. This part of the reservoir is filled with gas, which is permanently present in the UGS, during injection, at the stage of gas reception and after the storage has been emptied [11].

The active part of gas in the UGS consists of proper gas reserves stored in the underground gas storage (storing capacity) which can be used for commercial purposes. The active part of the storage can be filled with gas which is later received, depending on the demand.

The total storing capacity of storages located in porous media directly depends on the volume of the porous structure of the reservoir horizon. If the stored gas was located in the primary hydrocarbon deposit, the storing capacity was connected with the primary resources.

The working (active) capacity of the reservoir depends on the gas compressive value, i.e. maximal working pressure $p_{\max}$, which cannot exceed the initial reservoir pressure p_{lo} (pressure in the collector horizon) at the stage of injection, or mechanical strength of the horizon. The bigger is the range of pressure difference between the working pressure of gas storage $p_{\max}$ (filled) and $p_{\min}$ gas reception pressure (empty), the higher is the active capacity V_{akt} of the storage. The higher is the pressure $p_{\max}$, the higher is the initial reception capacity of the storage [12].

The efficiency and profitability of underground gas storages are determined by the passive (buffer) capacity. It maintains the required pressure in the storage, which is needed to guarantee the reception capacity of reception wells. In the presence of watered horizons in the neighborhood of the UGS, the passive part of gas in the storage maintains the water contour at a safe distance from the system of wells. The buffer volume of the storage depends on the type of deposit and the required operational parameters of the UGS.

The buffer volume (gas cushion) in the storage usually constitutes 45% to 60% total volume, and so the active volume of the storage is 40% to 55% its total volume. In storages located in old hydrocarbon deposits, the passive to active volume is generally 1 : 1. When the storages are organized in aquifers, the ratio is 2 : 1. The doubled buffer volume stems from the specific character of hydrodynamic problems related to aquifer energy in such reservoirs.

Considering the character of the activity associated with gas storing, the UGS operators should use it at the highest possible efficiency level, i.e. at maximal working parameters and acceptable investment and operational costs.

Originally the idea of building underground gas storages was necessitated by the need of balancing out seasonal changes in gas distribution networks. The present and future use of natural gas storages is broader than originally assumed and concentrates mainly on improving the efficiency of exploitation systems and their seasonal flexibility. They are a buffer for strategic reserves to be used in unexpected crisis situations, to periodically optimize the price oscillations on the gas market and dynamically react to the storing needs [13–16].

There exist justified needs of restructuring operational parameters of particular underground gas storages used in the Czech Republic.

The active capacity of UGS should be maximized. A small increase of the active storing capacity can be observed even after long-term exploitation of the storage due to the cyclic character of the storing process (i.e. gas injection/reception). In this process the storing collector gets ‘cleaned up’ from fine rock particles liberated during cyclic gas flows, thermal expansion, compressive stress or turbulent flow through the rock skeleton, drying of porous space in the collector [12].

When designing an underground gas storage (in depleted or partly exploited hydrocarbon deposits) the maximal and minimal working pressures ($p_{\max}, p_{\min}$) depend on original values of pressures in the deposit and their relation to the hydrostatic pressure at the depth of the deposit. The primary pressures are taken into account during initial exploitation of the UGS, and for the safety reasons, slightly lower pressure values are assumed.

After the cyclic use of UGS becomes regular, the working pressure can be increased by about 10% above the hydrostatic pressure or original reservoir pressure. This, however, should be preceded by the long-term monitoring of rock mass behavior around the collector, and analysis of factors which could refrain the working pressures from increasing (possible loss of rock mass tightness, see Fig. 2). Apart from monitoring the storage, also field and laboratory tests should be performed to create bases for optimal modeling of the UGS [17].

2. POSSIBLE WAYS OF INCREASING GAS STORING CAPACITY

The total storing capacity of underground gas storages can be increased by the low--capacity (A), and medium-to-high capacity (B) methods.

A. The low-capacity increase lies in increasing the capacity by a few million to tens million m^3, depending on the initial total capacity of a given UGS.
B. The medium-to-high capacity increase is measured in tens or hundreds million m^3, depending on the initial total capacity of a given UGS.

Ad A. The low-capacity increase variant is implemented for underground gas storages organized in hydrocarbon deposits and aquifers, when the gas storage has already exhibited its operational abilities, and the gas demand is still growing. It is assumed that the market gas demand will increase (from the storage point of view), and medium-to-high capacity increase variant is not ready yet, or cannot be implemented at all.
The storage structure (collector horizon or horizons) decides about the success of the capacity increase operation. Among other important factors are parameters of pipelines associated with the storage and capacity of the surface infrastructure. Moreover the operational capacity of injection/reception wells and surface infrastructure do not require complex modifications or significant investments. Working pressures of the storage stay within the values of the primary reservoir pressure or hydrostatic pressure.

The low-capacity increase of the underground gas storage can be obtained by:

1) increasing the injection (working) pressure, without increasing the porous space of the storage,
2) increasing the injection (working) pressure, simultaneously increasing the porous space of the storage,

Ad 1) The variant in which the working pressure of injected gas is increased can be used for the storing structures which are lithologically or tectonically limited. Bottom water or edge water do not appear in such structures, or are negligible. The possibility of incorporating new porous spaces to the gas storing process for this type of structures is usually minimal.

Ad 2) Analogous to the previous variant, the working pressure is increased. However in this case the porous space in enlarged in the storing structure. This variant can be used for structures with bottom water or edge water, when the storing structures are hydrodynamically connected with other geological horizons (e.g. Lobodice UGS in the Czech Republic). By increasing the injection pressure, water is pushed by the injected gas to the porous space, and thus obtained additional porous space increases the storage capacity. Prior to increasing the working pressures, one should analyze the effect of higher pressure on the displaced water in the context of UGS sealing (the storage is sealed by the expelled water). In such structures (when the conditions allow) the working injection pressure can be increased by about 5–10% above the original reservoir pressure or hydrostatic pressure (in relation to the given depth of deposition of the hosting horizon).

Ad B. The medium-to-high capacity increase can be realized in areas where appropriate geological structures are available for the construction of new gas storages or reconstruction of the existing ones. Such activities can be undertaken in view of the financial and economic feasibility, i.e. when the state and EU donations as well as an appropriate investor are available, when the gas demand has a long-term character, the forecast development of market gas prices is advantageous, the geopolitical situation is good, etc. This is connected with the long-term plans, which can be realized according to different scenarios, later to be corrected and implemented, depending on the market situation in a given period of time.

The medium-to-high capacity increase lies in incorporating new storing objects (proper geological hosting structures), lying above or under the existing storing horizons or incorporating new structures in the immediate vicinity (e.g. Třanovice UGS).

Another way of increasing the storing capacity values lies in elevating working pressures in the storages, where high injection pressures have not been used to create additional reserves yet. This method of increasing storage capacity is limited by the surface infrastructure and underground utilities of the existing storage. Their parameters may be on verge of their technical abilities. The modification of the surface infrastructure and a bigger number of injection/reception wells is inevitable and involved costly investments.

Another method of increasing the storing capacity of UGS and creating large-capacity objects lies in building quite new storages (e.g. Dambořice UGS).

The storing capacity of UGS can be increased only when the storing structures remain tight. Generally, the tightness of the underground part of a gas storage can be divided into primary (initial) and secondary, after various technological operations have been performed (anthropogenically modified) [6].

The primary tightness is connected with the tightness of geological structures hosting the gas storage. The tightness of the original structure (in the geological time perspective) is defined by the hydrocarbons trapped in its geological spaces and their original accumulation.

Prior to increasing the storing capacity by increasing operational pressures in a given UGS, the sealing of the storing structure and range of gas accumulation after injection to the storage should be analyzed. These data are determined and controlled with special reservoir engineering techniques, especially by modeling and monitoring of the pressure/volume loop (reservoir pressure decreases due to the compressibility).

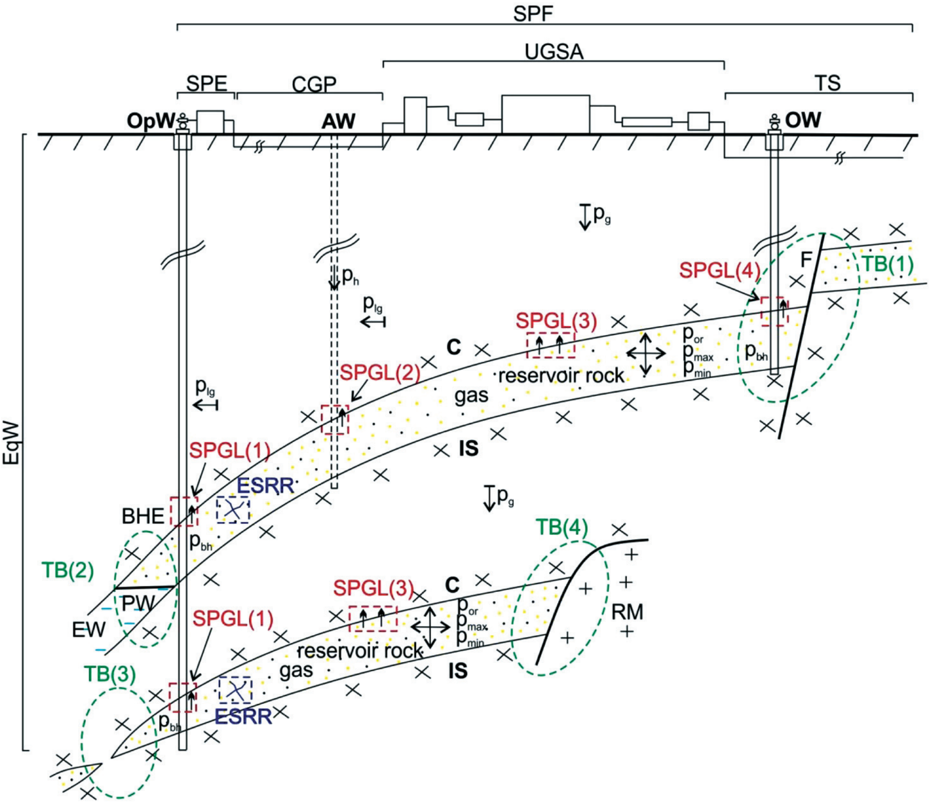
When evaluating the secondary tightness of a gas storage, one should check for the possible ways in which the natural (primary) tightness can be damaged by the anthropogenic activity. The loss of the primary tightness may be connected with the drilling jobs, well design and its performance, hardware and closing procedures. The tightness may be also lost in the course of extraction (e.g. secondary extraction methods) or storage (increasing storage volume). This may disturb the system of pressures in the rock mass and lead to the loss of natural tightness of the geological structure [17].

The potential hazards which may affect the tightness of storing horizons are reviewed in Figure 1, with geological (horizons distinction) and anthropogenic impacts indicated. The untightness associated with the tightness of the well mouth and bottom has not been discussed.

Among geological causes of the UGS untightness are the way in which collector strata are insulated/sealed, i.e. with a fault (ZOK1), aquifer reservoir (ZOK2), facial change (ZOK3) and overthrust of the rock mass (e.g. batholith) (ZOK4).

When analyzing anthropogenic factors we have places connected with injection/reception wells and monitoring wells, and more specifically: erroneously sealed casing in the reservoir intervals (MOT1 and MOT4), incorrectly closed old wells (MOT2), influence of pressure and temperature changes on the interface of the collector and impermeable caprock or subsoil (MOT3). Attention should be also paid to the possible loss of stability of the collector skeleton due to the changes of working pressure (cyclic change of pressure p_{max}–p_{min}) (OSK).

Among factors which may significantly affect the possibility of increasing storing capacity of a UGS are: loss of own stability of the collector and possible break in the impermeable caprock. These factors should be first checked before undertaking any decisions on increasing the capacity of a UGS with above discussed methods. The influence of properties of the collector horizons should be evaluated, e.g. with the mathematical modeling methods. The modeling will be reliable if the entry data come from laboratory experiments on rock samples (drilling core). The porosity of strata can be measured with the device owned by the Department of Engineering Geology and Institute of Clean Technologies VŠB-TU Ostrava. The parameters of reservoir rocks and caprock are analyzed with: multiphase permeameters BRP 350 and FDS 350, automatic permeameter and porosimeter Coreval 700 and reaction chamber RK-1 [18].



Key

SPF - surface plant facilities
SPE - surface production equipment
CGP - connecting gas pipelines
UGSA - UGS area
TS - transport system
OW - observation well
OpW - operating well
AW - abandoned well
EqW - equipment of well
BHE - bottom hole equipment
C - caprock
IS - impermeable seal
F - fault
RM - rock massif
formation water
PW - primary water
EW - edge water
↑ direction of possible gas leak

p - pressure
p_g - geostatic pressure
p_{lg} - lateral geostatic pressure
p_{or} - original reservoir pressure
p_{max} - maximal operating pressure
p_{min} - minimal operating pressure
p_h - hydrostatic pressure
p_{bh} - bottom hole pressure
TB - type of boundary
TB (1) - fault
TB (2) - water line
TB (3) - facial change
TB (4) - getting on different rock massif
SPGL - spots of possible gas leak (antropogenic influence)
SPGL(1) - defective bottom hole equipment of operating well
SPGL(2) - inadequate disposal of abandoned well
SPGL(3) - influence of pressure and thermal changes at contact of reservoir rock with caprock or impermeable seal
SPGL(4) - defective bottom hole equipment of observing well
ESRR - endanger of stability of reservoir rock

Fig. 1. Schematic of places threatened with the loss of tightness in underground gas storages – the effect of geological factors (primary tightness) and anthropogenic factors (secondary tightness)

3. CONCLUDING REMARKS

Nine underground gas storages are now operational in the Czech Republic (Fig. 2): UGS Třanovice, UGS Štramberk, UGS Lobodice, UGS Tvrdonice, UGS Dolní Dunajovice and UGS Háje belonging to Innogy Ltd., and two gas storages owned by MND Gas Storage Inc.: UGS Uhřice and Uhřice-South, as well as UGS Dolni Bojanovice by SPP Bohemia Inc. and UGS Dambořice owned by Moravia Gas Storage Inc.

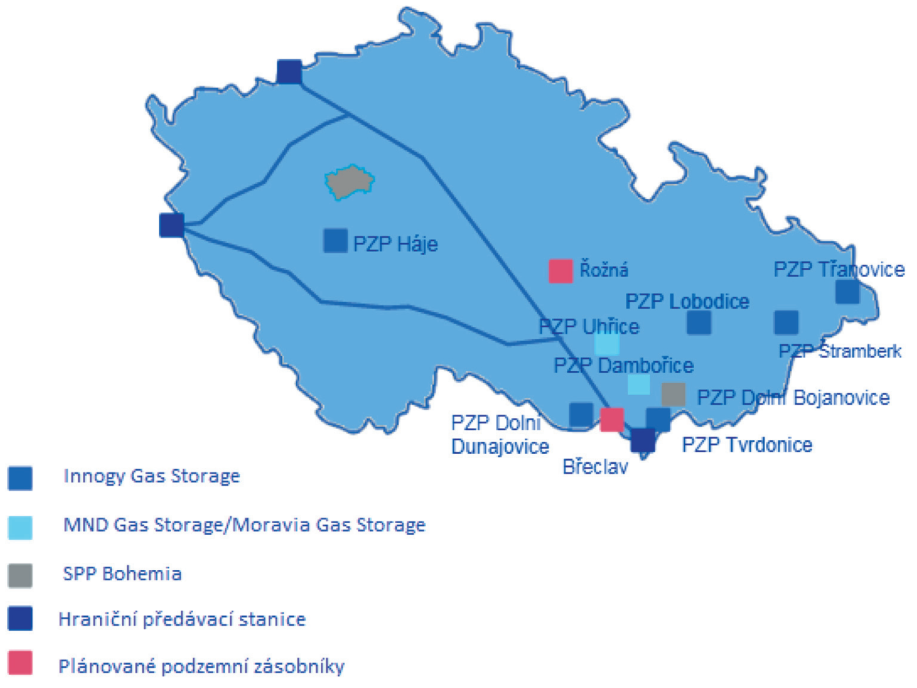


Fig. 2. Distribution of underground gas storages in the Czech Republic (NET4GAS)

The analysis of the present development of underground gas storages in the Czech Republic reveals that the low-capacity method of increasing storing capacity was used particularly in storages, which have been used for a long time. Further potential increase of their storing capacity based on elevated working pressures (variant "A") will require broader and more detailed laboratory analyses and modeling. The cost of the scientific and research works with the verification of the obtained results in real conditions will be very much higher then in variant "B", i.e. when successive collector strata are opened, wellbore and surface infrastructure is modernized, or new gas storages are built.

The more advantageous but much more expensive variant "B", where medium-to-high storing capacity increase can be attained has been already implemented in some UGS.

And so, new collector horizons located in the Sarmatian were added in the UGS Tvrdonice, and a new and independent collector horizon was separated from UGS Třanovice. In UGS Uhřice a separate geological storing unit Uhřice-jih was added. The method with which gas was injected to UGS Štramberk was modernized, where a new compression station was built. Originally this storage was fed by pressure coming from the distribution pipeline. In 2017 a new object was opened – it was UGS "Dambořice".

Besides, MND Gas Storage Inc. purchased two gas storages in Germany, i.e. UGS Stockstadt and UGS Hähnlein [19].

According to the forecasts, by 2021 the total storing capacity of the Czech Republic should amount to 3.7 mld m^3 at the daily gas reception capacity of 79 mln m^3. The operating capacity of the storages should be increased by ca. 0.7 mld m^3 as compared to the present value. The present total storing capacity of the UGS constitutes over 33% annual gas consumption in the Czech Republic. It was assumed that by the year 2021 the gas storing capacity should reach 40% the annual gas demand. The increase of the natural gas storing capacity in the Czech Republic is shown in Figure 3.

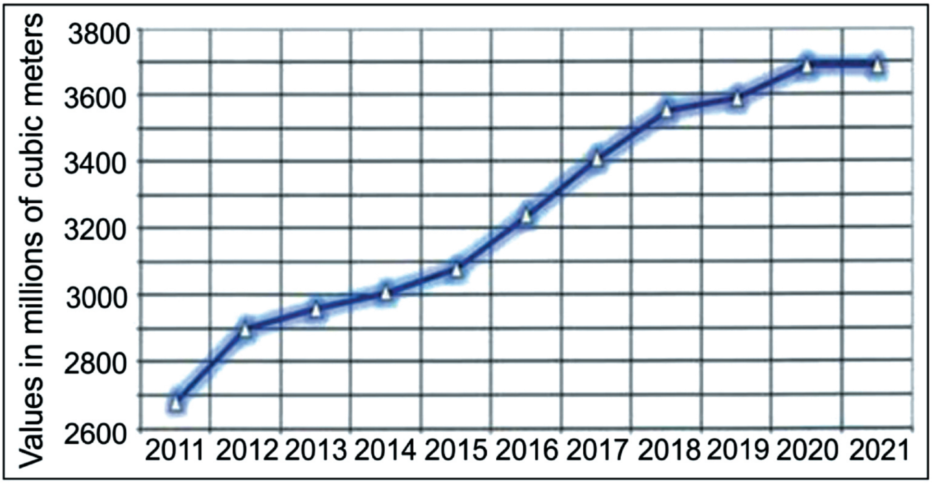


Fig. 3. Course and forecast of increase of natural gas storing capacity in the Czech Republic in the years 2011–2021

Apart from the measures undertaken to increase the present storing capacity for natural gas, also new storages are planned in Břeclava and Rožna. At present the realization of these projects has been suspended, questioning the assumed storing capacity increase in the Czech Republic.

In this situation other concepts are also considered to increase the storing capacity. Apart from the mentioned investments made by MND GS Inc. in Germany, talks about hiring storing capacities are in progress with Ukraine.

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