

THE STORAGE CAPACITY OF UNDERGROUND GAS STORAGES IN THE CZECH REPUBLIC

Jakub RYBA, Petr BUJOK, Martin KLEMPA

Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use, Faculty of Mining and Geology, VSB – Technical University of Ostrava,

708 00 Ostrava Poruba, Czech Republic

E-mail: jakub.ryba@vsb.cz

ABSTRACT

Sources of natural gas are in most cases located in remote areas far from the places where the gas is utilized, i.e. especially developed industrial countries to which it is transported via pipeline. However, transit gas pipelines, which are transporting extracted gas to the consumers, have a relatively limited peak capacity, the transit supplies essentially have a stable character and are not able to cover increased seasonal or peak demands for gas in gas distribution networks. The solution of this problem is the main task for underground gas storages (UGS) that through the operative regulation maintain stability and reliability of the entire gas system. This article provides a general list of options that can increase the storage capacity of natural gas in underground gas storages and focuses on factors that influence the options of an individual UGS.

Keywords: natural gas, underground gas storage (UGS), storage capacity

1 INTRODUCTION

Underground gas storages (UGS) became a necessary part of the gas transport system in all developed industrial countries. Although the initial implementations of these new technologies were used mainly to cover the seasonal consumption, their positive influence today affects the whole transport system due to an increase in consumption and the necessity to transport gas over increasingly longer distances. Relation of gas transport systems to the operation of UGS allows to attain the maximum capacity of gas pipes over the whole year [1,2,3]. The achievement of high utilization factor is carried over to “supplying” gas reservoirs which could employ injection/production wells at a higher degree due to the balanced regime and benefit from favorable development of exploitation regimes.

Underground gas reservoirs in their initial stages of development were built especially in depleted reservoirs of hydrocarbons [4]. However, depleted reservoirs were not always in the appropriate proximity from the place of concentrated gas consumption. In these cases, underground storages of mostly aquifer or cavern type [5,6,7] were created. For the schematic overview of UGS distribution in the Czech Republic, see Figure 1.



Figure 1. The scheme of distribution of UGS in the Czech Republic [8]

A total volume of gas in UGS (reservoir layers – storage horizons) can be divided into two basic parts – active and passive. The passive part is referred to as a basic filling, i.e. cushion gas. This part consists of gas that is permanently located inside an underground storage both during the withdrawal and after it [9,10,11]. The active part is the operational capacity of gas itself in UGS (so-called storage capacity), which is operatively injected and consequently withdrawn from the reservoir according to the demand of customers and for trade purposes. Total storage capacity, the size of the active and basic filling (cushion gas) belong to the basic parameters of UGS. Total storage capacity directly depends on the size of the pore volume of the reservoir layers. If the storage object is the original source of hydrocarbons, the total storage capacity is related to its initial volume.

The volume of cushion gas, which maintains the necessary pressure level for the preservation of operating performance of operating wells, has an impact on the efficiency and economy of UGS operations. In case primary or edge water is present, cushion gas also maintains an appropriate distance of contact water – gas from those wells. The volume of cushion gas depends especially on the character of a deposit and required parameters of UGS. Basic filling (cushion gas) generally makes 45 to 60 % of total capacity, therefore active filling mostly makes 40 to 55 %. At reservoirs located in the depleted deposits, it is aimed for the 1:1 ratio. For aquifer types of reservoirs, the ratio is usually 1:2 in favour of basic cushion with regard to specific hydrodynamic problems of this type of underground storage.

Due to the nature of gas storing activity, it is logically implied that it is in the interest of owners to operate UGS at peak effective level, i.e. at maximum operating parameters with appropriate investment and operative costs. Economic factors related to the purchasing and selling of natural gas will not be discussed in this article. Justification comes out from the fact that the original utilization of storage object was motivated mostly by the needs to maintain balance in the distributive network, while the contemporary and especially future utilization is predominantly focused on efficiency, flexibility and variability of stored volumes and significantly higher dynamics of the processes. Therefore, the justified needs of re-evaluating the currently applied parameters for individual storage objects are becoming apparent.

It can be derived from the characteristics of UGS operation that the storage capacities should be as large as possible. They can be slightly increased even during the long-term operation of the UGS by the influence of “cycling” the gas (injection, production), by the process of the so-called “purification” of collector (yield of fine mineral particles released by the heat dilation, pressure strain or eventually turbulent filtration from rock skeleton) and further by drying the pore space of the reservoir which contributes to the spontaneous increase of storage volumes [12,13,14].

During the designing of UGS operation (built inside the depleted or nearly depleted reservoirs of hydrocarbons), the values of operational pressures (p_{max} , p_{min}) are derived from the original data of the reservoir pressures and their relation to the hydrostatic pressure. These values are respected and, to increase safety during the initial operation of UGS, they are usually slightly undersized. After the transition to the regular cyclic operation

following the careful analysis of all underlying data, especially limiting factors (places of endangered tightness of reservoir, see Figure 2) and long-term experience from monitoring, field and laboratory research and modelling of the UGS operation, it is possible to suggest and, after the approval of respective institutions, to implement increase of upper range of operative pressures at up to approx. 10 % above the hydrostatic pressure (relative to the given depth level) or to the pressure of original deposit.

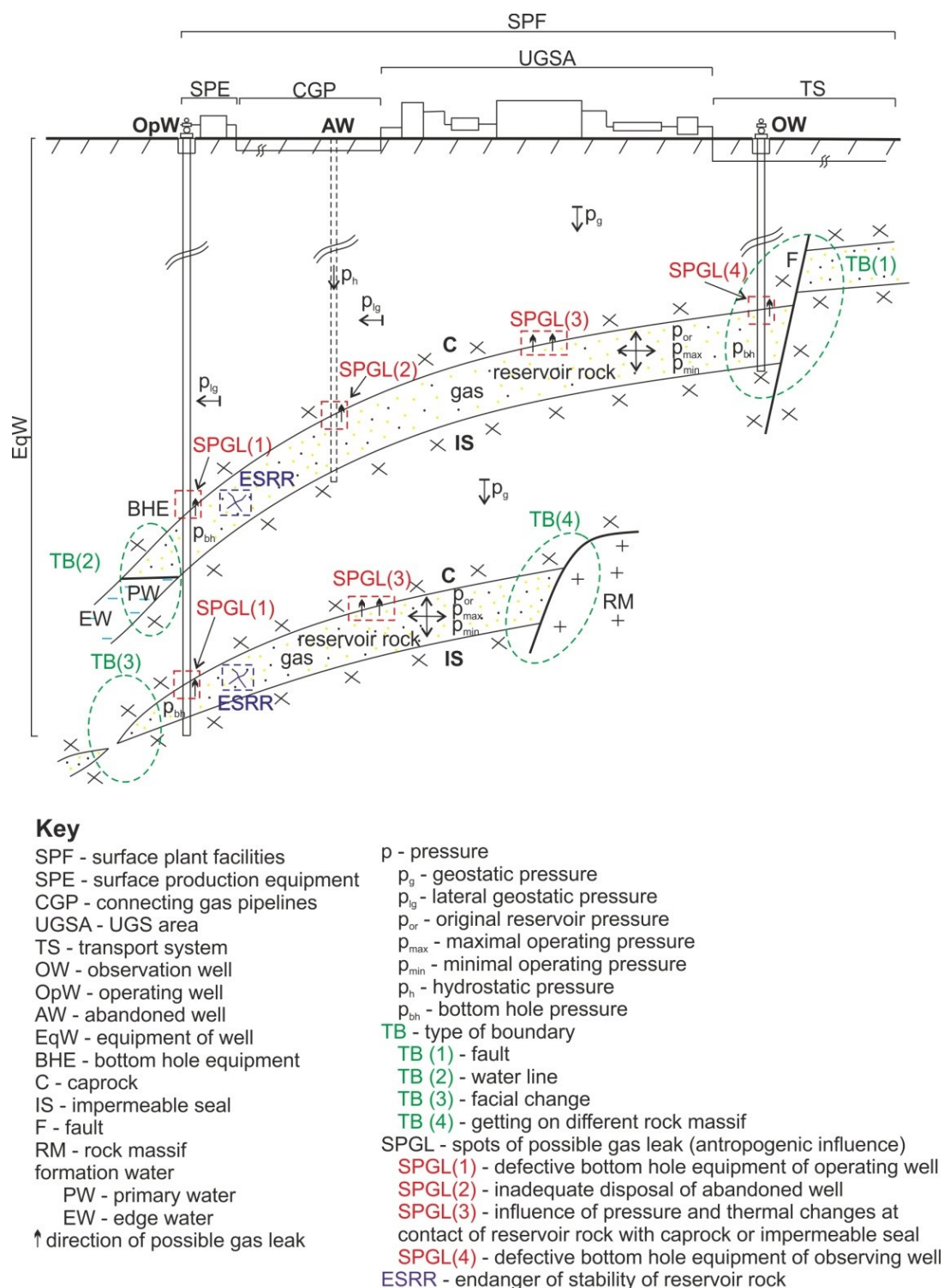


Figure 2. Places of endangerment of reservoir tightness – geological (primary hermeticity) and anthropogenic influences (secondary hermeticity)

2 OPTIONS OF INCREASING STORAGE CAPACITIES

The options of increasing total storage capacities of natural gas in UGS can be divided into two groups – “low” volume increase (A) and “medium to high” volume increase (B).

A. “Low” volume – increase in order of first millions to first tens of millions m³, according to the total storage capacity of given UGS.

“Small” volume increase is usually implemented at UGS utilizing original hydrocarbon deposits for storage purposes or aquifer structures in period when the UGS has already fully proved its functionality, the consumer’s demand rises, gas markets predict positive development (regarding storage) and “medium to high” storage increase is not prepared or is impossible to implement. The decisive factor of feasibility is the storage structure (reservoir’s layer or layers). Further related parameters of connecting gas pipelines and options of surface technologies are considered as suitable. Capacity parameters of operational wells, connecting gas pipes and surface technology do not require any complex adjustments, nor any significant investment into new functional devices (e.g. compressors). Operating pressures range from below original deposit pressure to below hydrostatic pressure.

This can be achieved by:

a) Only by increasing of operation pressures (i.e. an increase in operative maximum pressure and/or by a decrease in minimal operative pressure) with essentially minimal increase in pore space volume.

This method can be applied to the storage structures limited by lithology or tectonically. There is no primary nor edge water or it is eventually present in a negligible amount. The option of adding a new pore space to the process of gas accumulation is minimal.

b) Increase in maximum (operation) pressures connected with the increase in pore space volume.

This method of increasing impressing (operative) pressures is, in contrast to the method a), additionally connected to the increase in volume of communicating pores. It can be applied to the structures with bedding or outside water in the cases when they hydrodynamically communicate with other units (see e.g. UGS Lobodice). Via the increase in pressure, the water is pushed away, and the new pore environment is connected to the storage process. When assessing the options of increasing operative pressure, it is necessary to additionally (see point a) analyse the impact on the functionality of water sealing. Even in this case, it is possible (given the favourable conditions) to implement an increase in the maximum pressures at about 5 - 10 % above the original deposit pressure or hydrostatic pressure (in relation to the given depth level).

B. “Medium to high” volume – increase in the order of tens or first hundreds of millions m³, according to the total storage capacity of evaluated structures.

“High to low” volume increase can be implemented in suitable areas (more object structures) given the favourable conditions (state subsidies, EU subsidies, suitable investor, long-term increase in demand, predicted favourable development at gas market, favourable geopolitical development, etc.) according to the long-term project plans of construction (referred to as “stages”). These “stages” of increasing operative storage capacities can be multiple and can vary according to the different scenarios, which are adjusted to a specific situation in the given period.

“Medium to high” volume increase consists of the connection of new storage objects (appropriate reservoir’s layers) in the overburden or in the base of currently utilized horizons, eventually in the connection of new appropriate structures in the immediate surroundings (see e.g. UGS Třanovice). A further option is to significantly increase operation pressures at objects, where the “reserves” have not been fully utilized by achieving limit pressures so far. Implementation of this intent is limited by the parameters of surface plant technology and, outside of its structures, by parameters of connected gas pipeline systems which could have reached the limits of their capacity. The adjustment of surface plant technology, connections and adding of operation wells are usually inevitable and require substantial investment.

Another option of increasing the total storage capacity of natural gas regarding the needs of the entire country is represented by the construction of new storage objects (see UGS Dambořice). However, the increase in storage capacity can be implemented only when the hermeticity (tightness) of storage structures is preserved. Generally, the hermeticity of UGS underground part is divided into primary hermeticity (original) and secondary hermeticity, caused by technical operations (i.e. the anthropogenic activity of people) [14,15].

Primary hermeticity is related to the tightness of deposit objects, which is evidenced by the existence of primary deposit trap saturated by hydrocarbons (hermeticity in the dimension of geological time). In the case of over-pressurising during the process of UGS development, it is necessary to possess knowledge of the structural sealing and the extent of gas accumulation after pressurising of the reservoir. These parameters are determined and controlled by specialized reservoir and engineering methods – especially by modelling and observation of so-called p/z curves (deposit pressure reduced by the compressibility factor). For the assessment of secondary hermeticity, we observe disruption of primary hermeticity by anthropogenic activity and that either directly – by drilling and consequent inadequate equipment of wells (during their operation or after their liquidation) or

indirectly – by excessive increase in reservoir pressure (related to the increase of total volume of stored gas), which causes disruption of original geological seals.

The overview of areas, where the tightness of reservoir is endangered, is shown in Figure 2. It clearly presents both geological influences (caused by the borders of reservoir) and influences caused by human activity (anthropogenic influences). The issues of tightness related to the bottom hole equipment and the surface production equipment are not discussed further in this paper.

Types of boundary of a reservoir can be divided into fault boundary, primary or edge water boundary, facial change and getting on a different rock massif. Among anthropogenic influences we sort – imperfect implementation of bottom hole equipment of operation or eventually observation wells (including cementing of production casing), insufficiently liquidated old wells, the influence of pressure and temperature changes on the contact of a collector – caprock or impermeable base, endanger of geomechanical stability of reservoir due to the changes of operative pressures (cycling of p_{\max} - p_{\min}).

3 DETERMINATION OF FACTORS LIMITING AN INCREASE IN STORAGE CAPACITIES

Among significant factors that can affect the feasibility of increasing storage capacity, we may list the failure of geomechanical stability of storage object, the possible disruption of tightness of caprock and underlying impermeable seals and the failure of insulative properties of cementation. These factors should be prioritised and evaluated by both mathematic modelling and by laboratory research of corresponding rock (drilling cores) or, eventually, analogical samples.

Laboratory research aimed at the objectives listed above is enabled by top-quality apparatus (especially from French company Vinci Technologies [16]) and it can also be conducted in the laboratories of the Department of Geological Engineering and the Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use.

To determine an effective porosity and absolute permeability, it is possible to utilize the automatic permeameter and porometer Coreval 700. To assess a phase permeability (gas-water), a multiphase permeameter FDS 350 or a multiphase permeameter BRP 350 (see figure 3) can be used.

The determination of permeability (multiphase) is possible to conduct at rock samples (cores) at diameter 2.54 (1") and 3.81 (1,5"), length up to 7.62 cm at required pressure depressions (in order of first tens of MPa). The compression of the sample (core) in a sealing sleeve – which represents lateral geostatic pressure, can reach up to 35 MPa at layered deposit temperature up to 150 °C in apparatuses BRP 350 and FDS 350.

By adjusting the apparatus, it can be used to observe the influence of a cyclic effect of operating pressures (p_{\max} , p_{\min}) during the cyclic operation of UGS on the stability of reservoir's rock skeleton, i.e. on the influence on the impermeability of caprocks.

Long-term influence of layer waters on the quality of cement stone can be checked at "in situ" conditions (pressures up to 16 MPa, temperature up to 80 °C) directly at the area of contact rock-casing-cement in the reaction chambers RK-1 of own construction (paten no. 306 107). We can also use a test cell for samples (functional sample reg. no. 101/06-12-2011_F) developed specifically for this purpose, which enables the simulation of reservoir environment at laboratory-prepared samples.

Currently, the laboratories listed above are conducting long-term research focusing on the cycle operation of UGS. The measurements can check the geomechanical properties of rocks that have a decisive influence on the considerations about the further development of storage capacities and safe operation of UGS. This includes especially the research of the influence of cycling maximal (p_{\max}) and minimal (p_{\min}) operating pressures on geomechanical stability of rocks skeletons (storage and seals) and determination of "pressure" limit of integrity failure.

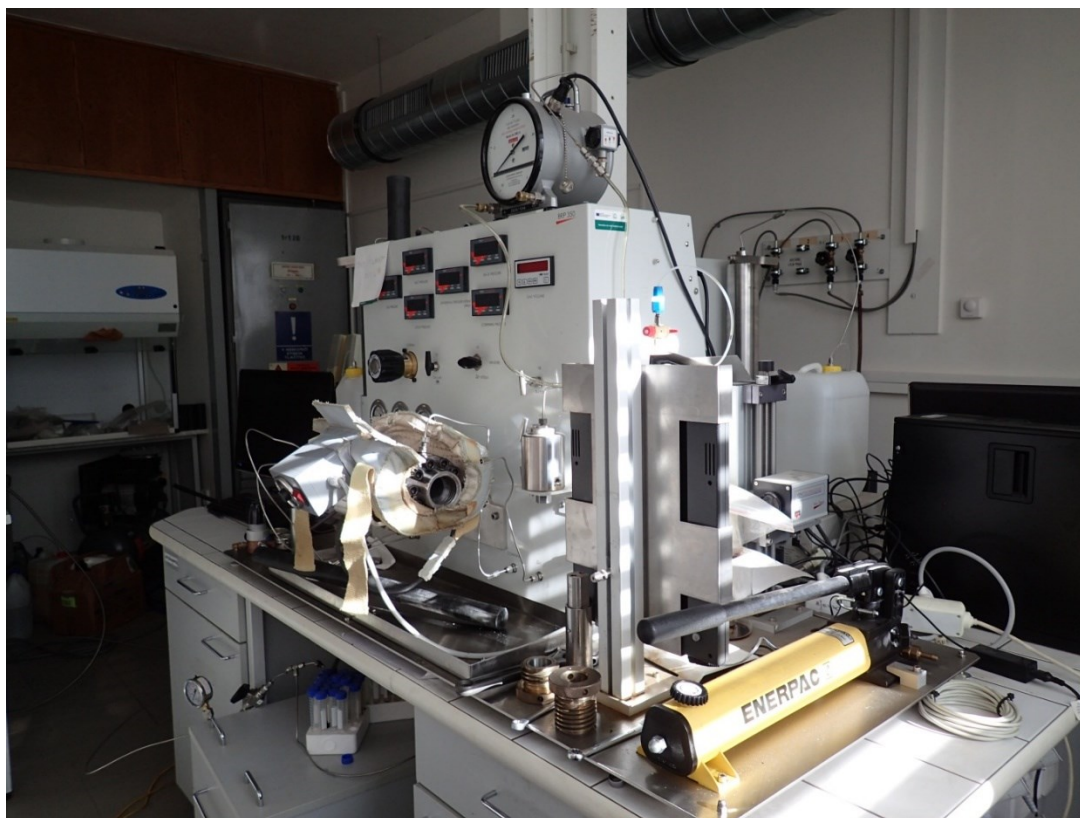


Figure 3. Benchtop Relative Permeameter BRP 350 (Klempa, 2018)

4 CONCLUSIONS

To date, there are the following UGS in the Czech Republic (for location see Figure 1): UGS Třanovice, UGS Štramberk, UGS Lobodice, UGS Tvrdonice, UGS Dolní Dunajovice and UGS Háhe (innogy s.r.o.); UGS Uhřice and Uhřice-jih (MND gas Storage a.s.); UGS Dolní Bojanovice (SPP Bohemia a.s.); and UGS Dambořice (Moravia Gas Storage a.s.).

Based on the evaluation of the existing development of natural gas storage in UGS, we can state that the possibilities of “low” volume increase in storage capacities have been already partially implemented at the long-term operating reservoirs. If we reason conservatively about average option of increasing total storage capacities at 5 %, then the outcome could be estimated at approx. 154 million m³. A further increase via this method would require conducting a higher amount of laboratory research. The expenditures for conducting these laboratory simulations and validating these alternatives are incomparably lower than the preparations of listed alternatives “B”.

More progressive alternatives of type “B” have been already implemented at some areas which include UGS Tvrdonice (connecting new Sarmatian horizons) UGS Třanovice (connecting new separate deposit object in immediate surroundings); UGS Uhřice (connecting new separate deposit object – Uhřice-jih); UGS Štramberk (installing compressor station, originally the injection was realized only via the overpressure from distributive gas pipeline). The newest UGS Dambořice was put into operation in 2017.

The overview of individual UGS and their technical parameters in the Czech Republic (situation in 2016) is listed in Table 1 [17].

Table 1. Technical parameters of individual UGS in the Czech Republic [17]

Operator	UGS	Storage Capacity mil. m ³	Maximum withdrawal capacity mil. m ³ /day	Maximum injection capacity mil. m ³ /day
innogy GS	Háje	64	6.0	6.0
	Dolní Dunajovice	900	17.0	12.0
	Tvrdonice	535	8.0	8.0
	Lobodice	177	5.0	2.5
	Štramberk	500	7.0	7.0
	Třanovice	530	8.0	6.0
	Total	2 706	51.0	41.5
MND GS	Uhřice	255	6.0	2.6
Moravia GS	Dambořice	115	4.0	3.0
Czech Republic total		3 076	61.0	47.1
SPP Storage, Ltd. (connection to Slovak gas pipeline system)	Dolní Bojanovice	576	9.0	7.0

It has been estimated that by 2021 the total storage capacity should reach the value of 3.7 billion m³ with daily withdraw capacity of 79 million m³ in the Czech Republic. In comparison to the current state, this would mean an increase in operative volume by approx. 0.7 billion m³. The total storage capacity of UGS represents more than 33 % of yearly consumption. It had been supposed that around 2021 the capacity of gas storage (especially due to the new connected objects) could reach up to 40 % of yearly gas consumption [8].

Even other gas companies had planned the construction of new gas storage capacities in the Czech Republic. New UGSs were supposed to be built in Břeclav area and in Rožná na Žďársku. However, the realization of these projects is halted, and it is probable that the prognosis mentioned above will not be achieved.

However, the requirements for increasing storage capacity by industrial companies or distribution companies can also be resolved by storing gas in UGS situated abroad (see UGS operated by MND a.s. in Germany). The utilisation of local storage capacities for the needs of the Czech Republic was also offered by Ukraine.

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